G.E.C. Journal

VOL. X. AUGUST, 1939 No. 3.

CONTENTS

PAGE

FRONTISPIECE: A FLOODLIGHTED SCENE AT THE ALDERSHOT TATTOO – – – – – – – – – – 156

COGGING MILL MODERNIZATION AND NEW MERCHANT MILL INSTALLATION (DORMAN, LONG & CO., LTD.) – – – 157
By The Technical Staff of Dorman, Long & Co., Ltd.

COLOUR AND COLOUR RENDERING – – – – – 172
By C. C. Paterson

INSTRUMENTS INCORPORATING THERMIONIC VALVES, AND THEIR CHARACTERISTICS—PART II. – – – – 183
By E. G. James, G. W. Warren and G. R. Polgreen

PLASTICS AND THE ELECTRICAL INDUSTRY – – – 192
By A. E. Phipps

THE ELECTRICAL EQUIPMENT OF TRINIDAD PAPER PULP MILL 199
By J. F. Prince

A UNIDIRECTIONAL SYSTEM FOR THE LIGHTING OF DOUBLE-CARRIAGEWAY AND ONE-WAY ROADS – – – – 205
By J. G. Christopher, J. B. Smyth and J. M. Waldram

THE DESIGN OF FRACTIONAL HORSE-POWER MOTORS—PART I. 212
By N. F. T. Saunders

Published quarterly by

THE GENERAL ELECTRIC Co., LTD.
Magnet House, Kingsway, London, England.

COPYRIGHT.

PRICE 1/-

Copies may be obtained from the above address.

A FLOODLIGHTED SCENE AT THE ALDERSHOT TATTOO.

The illuminations for the Aldershot Tattoo, 1939, were arranged in collaboration with the G.E.C. In the centre of the scene illustrated is a statue of Sir Francis Drake which is illuminated by fluorescent materials activated by "Osira" black lamps. The background is illuminated by "Osira" floodlighting lamps.

G.E.C. Journal

VOL. X. AUGUST, 1939. No. 3.

Cogging Mill Modernization and New Merchant Mill Installation.

COMPREHENSIVE RECONSTRUCTION AND EXTENSIONS TO ROLLING MILL EQUIPMENT AT THE CLEVELAND WORKS OF DORMAN, LONG & CO., LTD.

By the Technical Staff of Dorman, Long & Co. Ltd.

EXTENSIONS of a comprehensive character involving plant reconstruction on a large scale have been made during the past few years to the Cleveland Iron & Steelworks, Middlesbrough, of Dorman, Long & Co., Ltd. This work has of necessity included important modifications and additions to the original rolling mill equipment, among which the modernization of an electrically driven 40in. reversing cogging mill and the installation of a new five-stand light section mill are two of the most important. The cogging mill electrification was undertaken with the object of providing bloom producing capacity in addition to that supplied by the existing nearby steam driven cogging mill, while

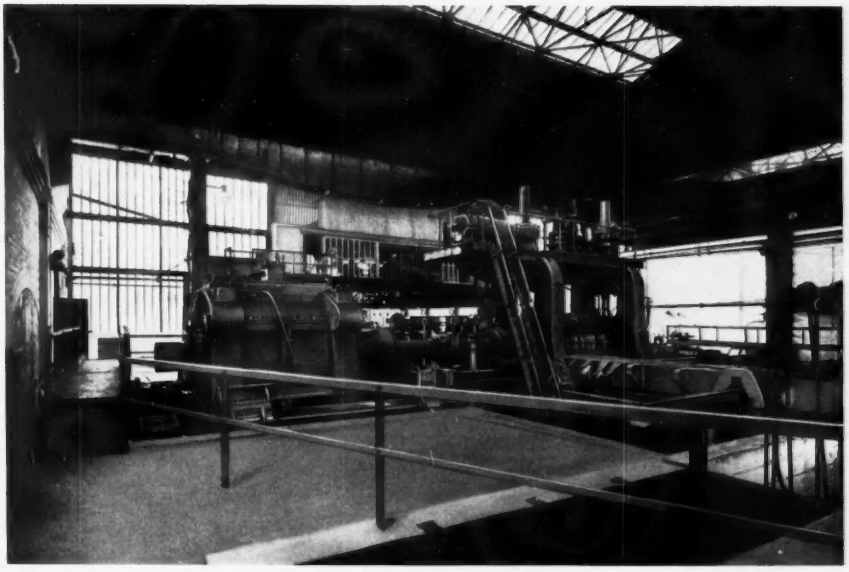


Fig. 1.—Rear view of 40-inch cogging mill driven by the 6,000/17,000 h.p. D.C. motor shown in figs. 5 and 6.

The background is illuminated by "Osira" floodlighting lamps.

Fig. 2.—Another view of the 40-inch cogging mill, taken from the front and showing the hydraulic manipulators.

the new light section mill was installed to increase the Company's production capacity of small merchant bar sections.

The electrical equipment for both the cogging mill and the merchant mill was designed and manufactured at the Witton Engineering Works of The General Electric Co., Ltd., and the mechanical portion of the merchant mill was designed by Schloemann Aktiengesellschaft of Düsseldorf. Although of German design, most of the mechanical portion was constructed in this country by the Fraser & Chalmers Engineering Works of the G.E.C. at Erith, Kent.

In the following description it is proposed to describe, first, the 40in. cogging mill and, secondly, the merchant mill with particular reference in each case to the associated electrical equipment.

40-inch COGGING MILL.

The cogging mill (figs. 1 and 2) was originally installed in 1916, and its electrical driving equipment consisted of an Ilgner set and a double armature main mill motor. In 1932, this electrical equipment was removed and transferred to a 32in. two-stand reversing section mill, known as No. 6 mill, the two stands of which were driven by the mill motor in place of an obsolete steam engine. This was achieved by dividing the double armature mill motor into two main driving units and augmenting the Ilgner set by the addition of a further generator and induction motor. Subsequently it became necessary to reintroduce into service the 40in. cogging mill. Work on the reconstruction was started in the autumn of 1936, and the first ingot was cogged in the reconstructed mill in the early part of April, 1937.

Buildings and Foundations.

A general layout of the mill and bloom banks is shown in fig. 4. The modifications and additions to the existing plant have included the installation of four modern Stein & Atkinson soaking pits, fig. 3, on the site previously occupied by old floor-level type pits. Each of the new pits has a capacity of twelve 3½ ton ingots and the soaking pit bay has been arranged to allow for additional pit capacity.

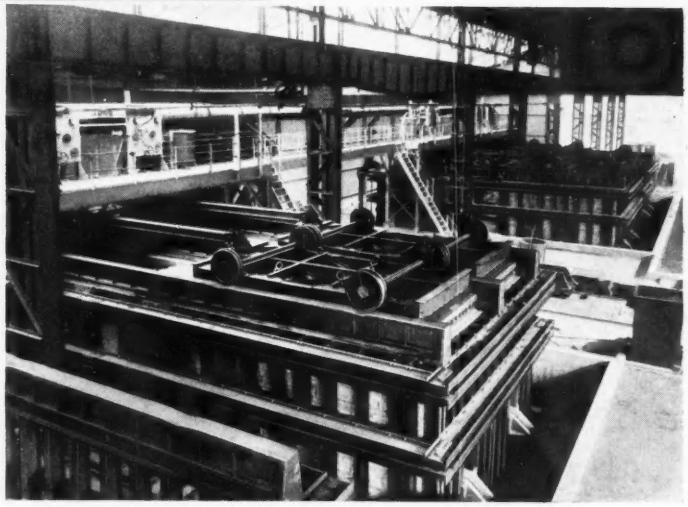


Fig. 3.—New soaking pits installed on the site previously occupied by old floor-level pits.

The existing main mill motor and Ilgner set foundations were partially incorporated in the fresh foundations required for the new and heavier electrical equipment of the main drive.

Mechanical Improvements.

In addition to the new electrical equipment, which is described later in this article, a considerable number of mechanical modifications and improvements were introduced into the mill and its auxiliaries. Modern universal spindles and an improved method of supporting the top spindle were incorporated in the mill drive as shown in fig. 1, together with a new arrangement for roll changing and forced feed grease lubrication of the roll neck bearings which replaced the plain bronze bearings. The new bearings

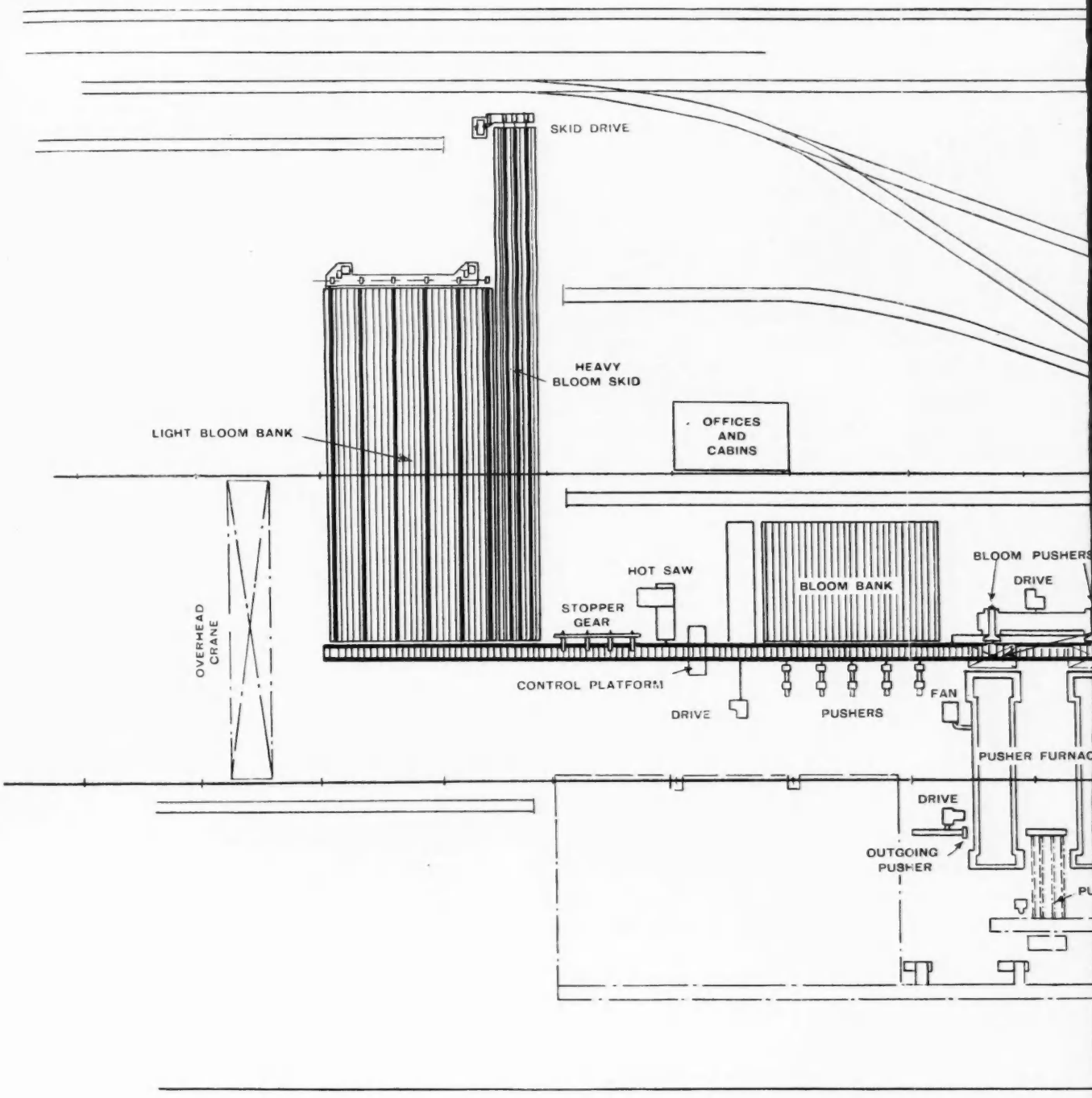

SKID DRIVE
HEAVY
BLOOM SKID
LIGHT BLOOM BANK
OFFICES
AND
CABINS
OVERHEAD
CRANE
HOT SAW
STOPPER
GEAR
BLOOM BANK
BLOOM PUSHERS
DRIVE
CONTROL PLATFORM
DRIVE
PUSHERS
FAN
PUSHER FURNAC
DRIVE
OUTGOING
PUSHER

Fig. 4.—Layout

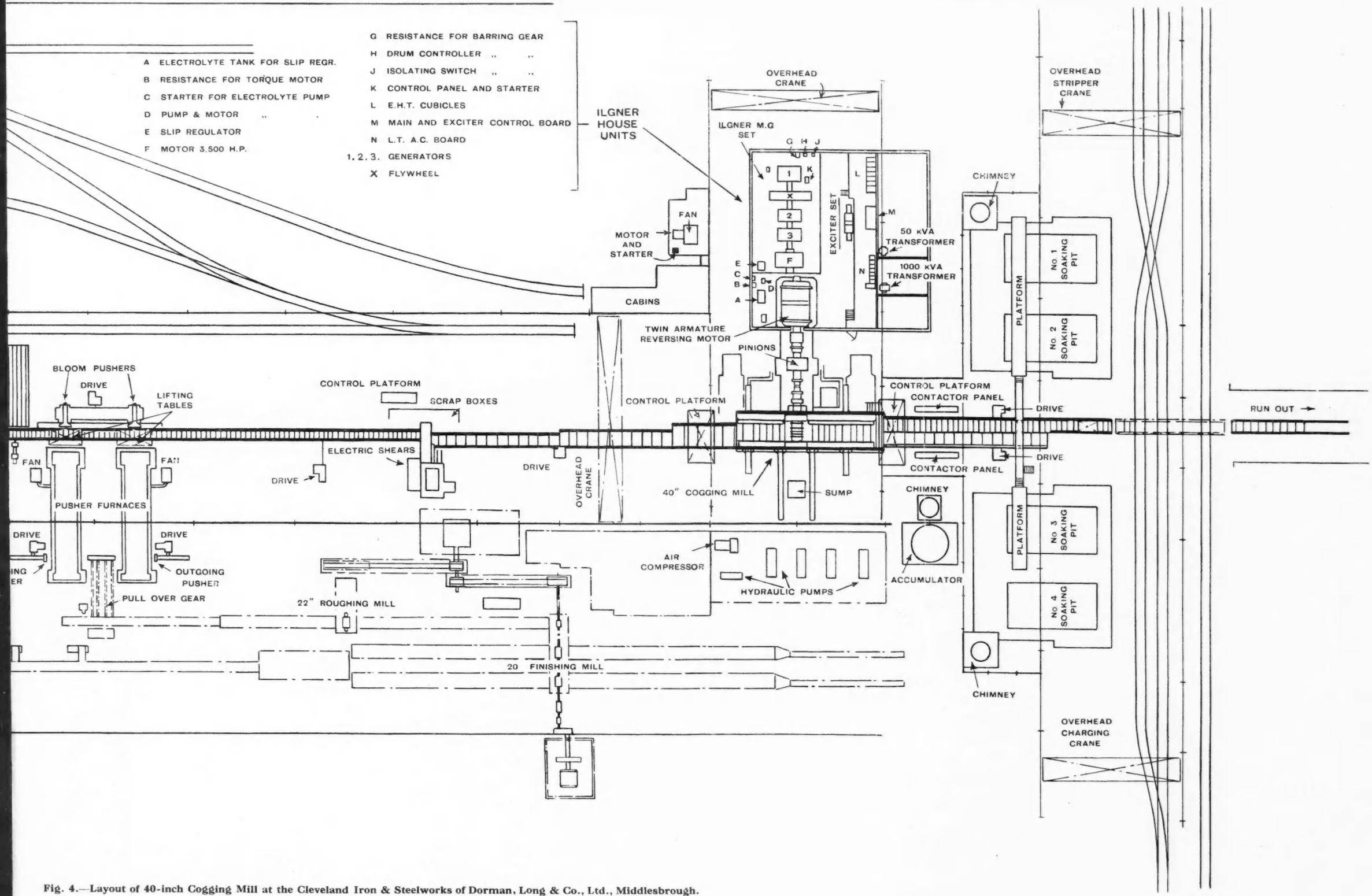


Fig. 4.—Layout of 40-inch Cogging Mill at the Cleveland Iron & Steelworks of Dorman, Long & Co., Ltd., Middlesbrough.

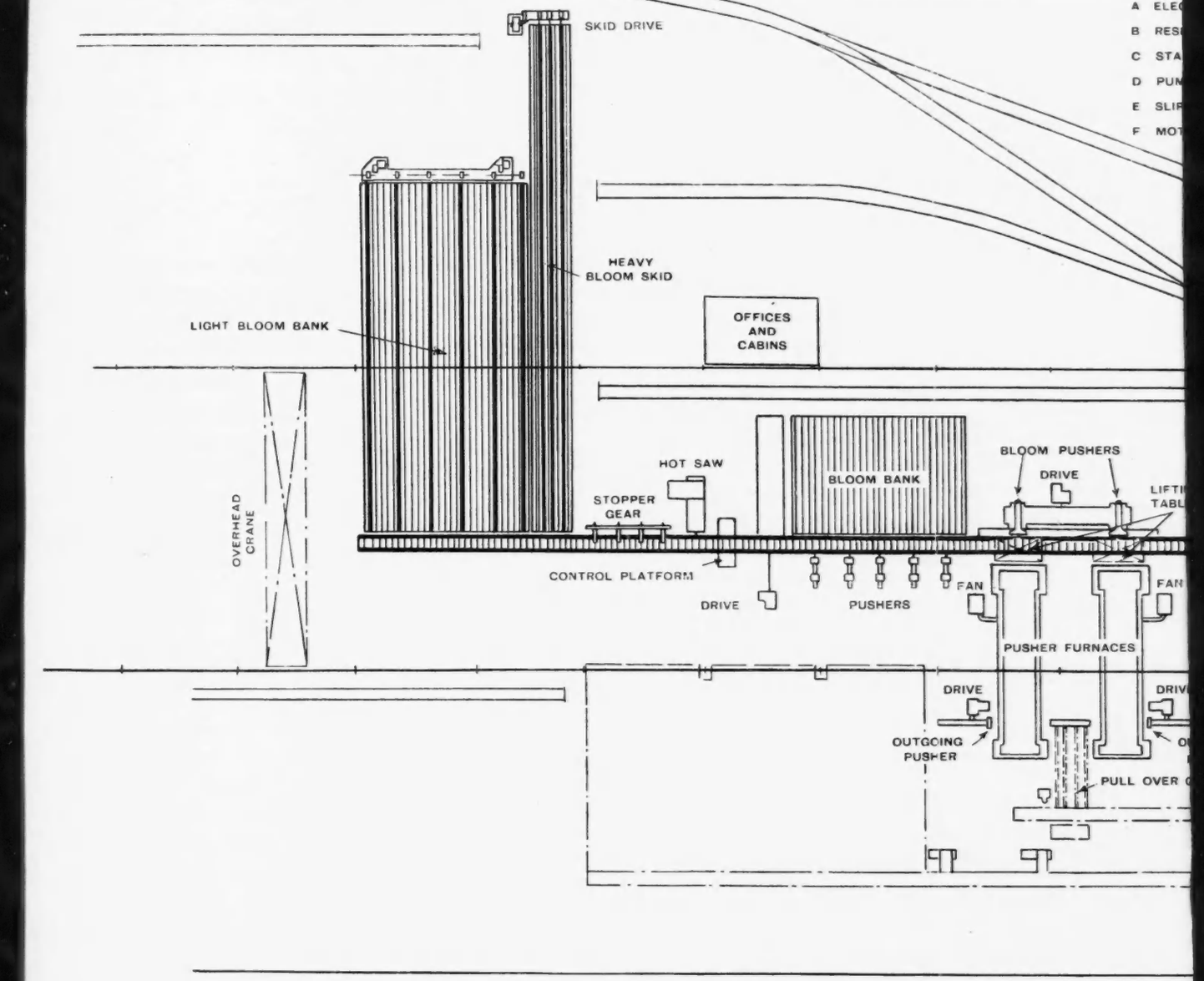


Fig. 4.—Layout of 40-inch

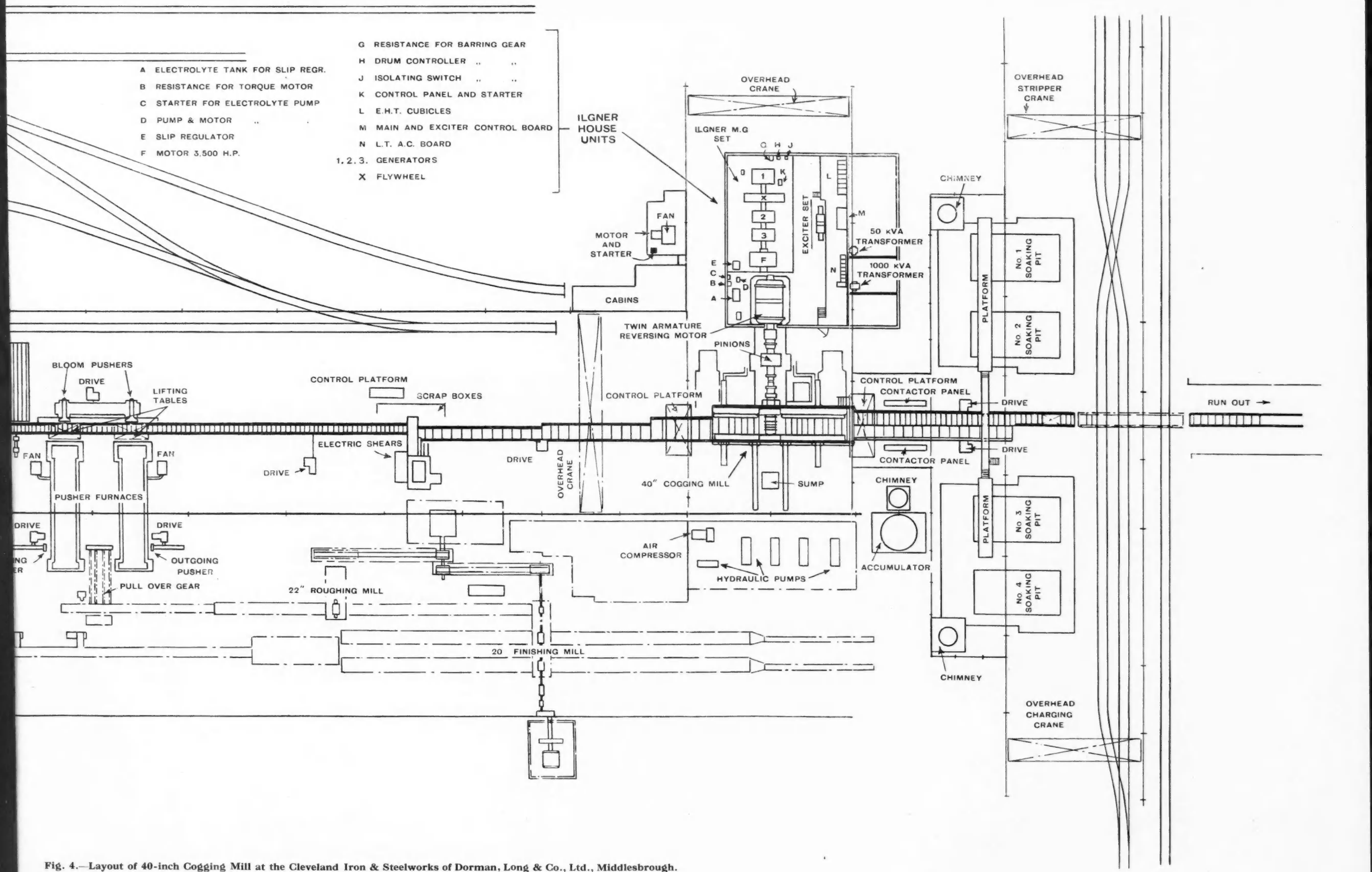


Fig. 4.—Layout of 40-inch Cogging Mill at the Cleveland Iron & Steelworks of Dorman, Long & Co., Ltd., Middlesbrough.

consist of water-cooled white metal chocks lubricated by grease which is fed under pressure from a motor driven grease pump situated on top of the roll stand.

In order to increase the speed of working of the mill, a 200 h.p. motor has been installed on the screwdown gear, and the speeds of the live rollers at the front and rear of the mill have been increased by 68 per cent.

Fig. 5.—6,000/17,000 h.p. (20,000 h.p. peak load) double armature reversing D.C. motor 1,600 volts, driving the 40-inch cogging mill: speed range, 150/0/150 r.p.m. The Ilgner set is seen in the background.

Handling Facilities.

In addition to supplying the new light section mill, the cogging mill also feeds 6in. blooms to a three-stand three-high medium section mill in the adjoining bay, the remainder of the production being chiefly sale blooms of the same size. For the handling and export of this material, two new hot bloom banks shown on the extreme end of the run out track in fig. 4 were installed in a new building extension provided with loading facilities. The capacity of the mill drive is illustrated by the performance of the mill itself, a 3½-ton ingot being reduced in 17 passes

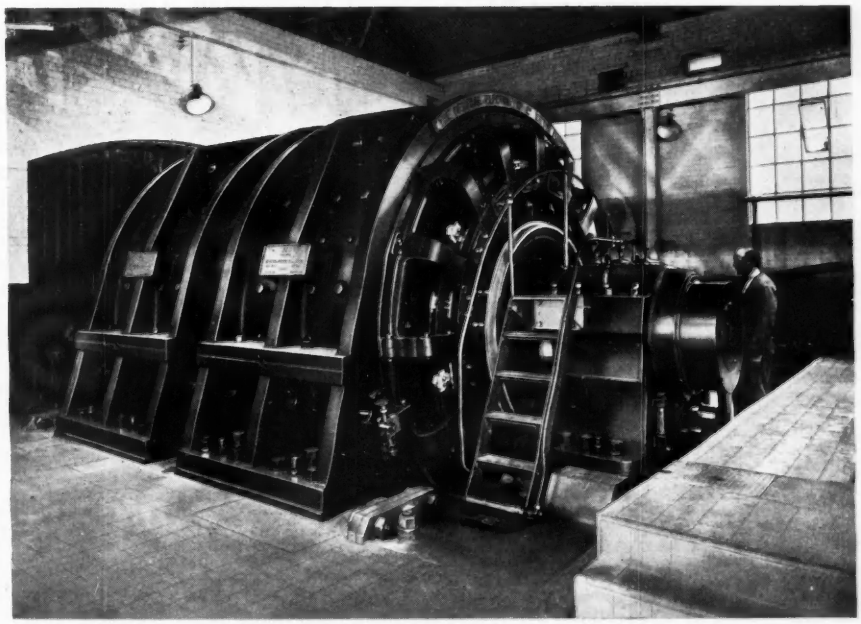


Fig. 6.—Another view of the 40-inch cogging mill driving motor.

to a 6in. bloom in 2½ minutes. As the maximum "throughput" of the soaking pits so far installed is only sufficient to meet the present production requirements, and as these are considerably less than the mill capacity, no figures are available indicating the continuous production performance of the mill.

Fig. 7.—Flywheel Ilgner set comprising a 3,500 h.p. induction motor driving three 1,580 kW D.C. generators and a 40-ton flywheel.

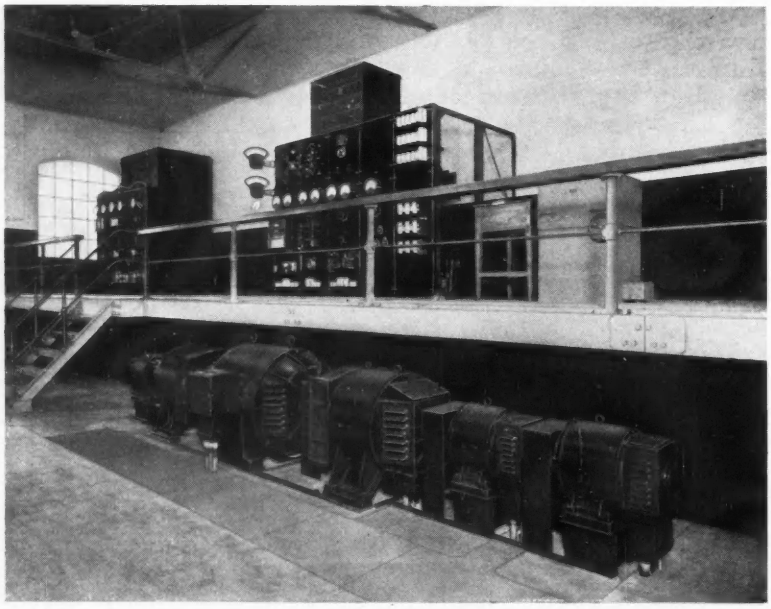


Fig. 8.—A.C. and D.C. switchgear in the main motor room and, in the foreground, an exciter set for the generator fields and the mill motor fields.

ELECTRICAL EQUIPMENT.

The mill driving motor, together with its associated equipment, is housed in the motor room adjacent to the mill. Views in the motor room showing the main mill motor, an Ilgner set and switchgear are shown in figs. 5 to 8 inclusive. The main drive is a 6000/17000 h.p. 1600 volt D.C. reversing mill motor having a speed range of 150/0/150 r.p.m. supplied with current from an Ilgner set which comprises a 3500 h.p. slipring motor coupled in tandem to three 1580 kW 530 volt generators and to a 40-ton flywheel.

Main Mill Motor.

In designing the mill motor it was estimated that to perform the duty required a peak output of 17,000 h.p. would be necessary and a speed of 150 r.p.m. The motor is actually capable of a peak output of 20,000 h.p. The speed of the motor from 0/60 r.p.m. in either direction is obtained by Ward-Leonard control and for 60/150 r.p.m. in either direction by shunt control. The motor stator casing and bedplate, together weighing 96 tons, were fabricated in the Welding Department of Dorman, Long & Co. Ltd.

The motor (figs. 5 and 6) is a double unit, the two separate armatures being coupled back-to-back by means of a large diameter rigid coupling unsupported by any middle bearing. This type of construction was chosen on account of the restricted space available on the foundations.

One of the chief features in the mechanical design of the motor is the special form of construction employed to deal with the large stresses set up by the rapid reversal of the armatures. This reversal takes place from top speed in one direction to top speed in the opposite direction in 3½ seconds, and from 60 r.p.m. in one direction to 60 r.p.m. in the opposite direction in 2 seconds. In view of the fact that each armature has a diameter of 9ft. and weighs 44 tons, some idea will be gained of the stresses imposed on the armatures themselves and the supporting framework. The following brief particulars of the mechanical design will therefore be of interest.

The total weight of the motor is 260 tons. The armature stampings are secured to the armature

hub by means of dove-tailed keys and the complete assembly is held between two cast steel endplates. Fingers of I section are welded on to ensure that the outer periphery of the core is tightly clamped. Each armature hub is of cast steel and is provided with a flange at one end for coupling the armatures together by means of large fitted bolts. The shell is of exceptionally heavy fabricated construction and is split on the horizontal centre line to provide access to the armature and the windings and for ease in handling. The two large bearings are supported on cast steel pedestals, the journals having a diameter of 27ins. In view of the possible fracture of a mill spindle and the consequent abnormal end thrust which would occur, the mill end bearing is provided with a thrust plate. Further, the bolts securing the pedestal of this bearing extend down through the bedplate into the foundations so that any thrust which may be imparted by the mill is taken by the foundations.

Each bearing has three large oil rings, the lubrication so obtained being assisted by an auxiliary oiling system in which oil is pumped into the bearing cap and poured on to the rings, surplus oil being drained back to the supply tank.

The motor is ventilated by a separate external fan, driven by means of a 105 h.p. 960 r.p.m. motor delivering 50,000 cubic feet of air per minute at a static water gauge pressure of 6ins. The air is drawn through a self-cleaning rotating filter situated in an air tight chamber, and is discharged into a duct leading to the centre of the motor. Thence the air passes through the armatures and fields of the motor and is finally discharged at both ends.

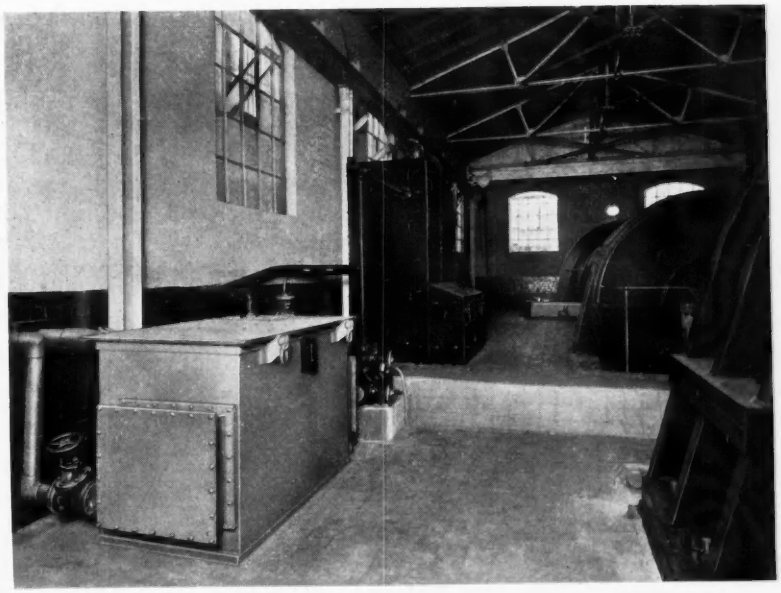


Fig. 9.—Slip regulator and electrolyte cooling tank.

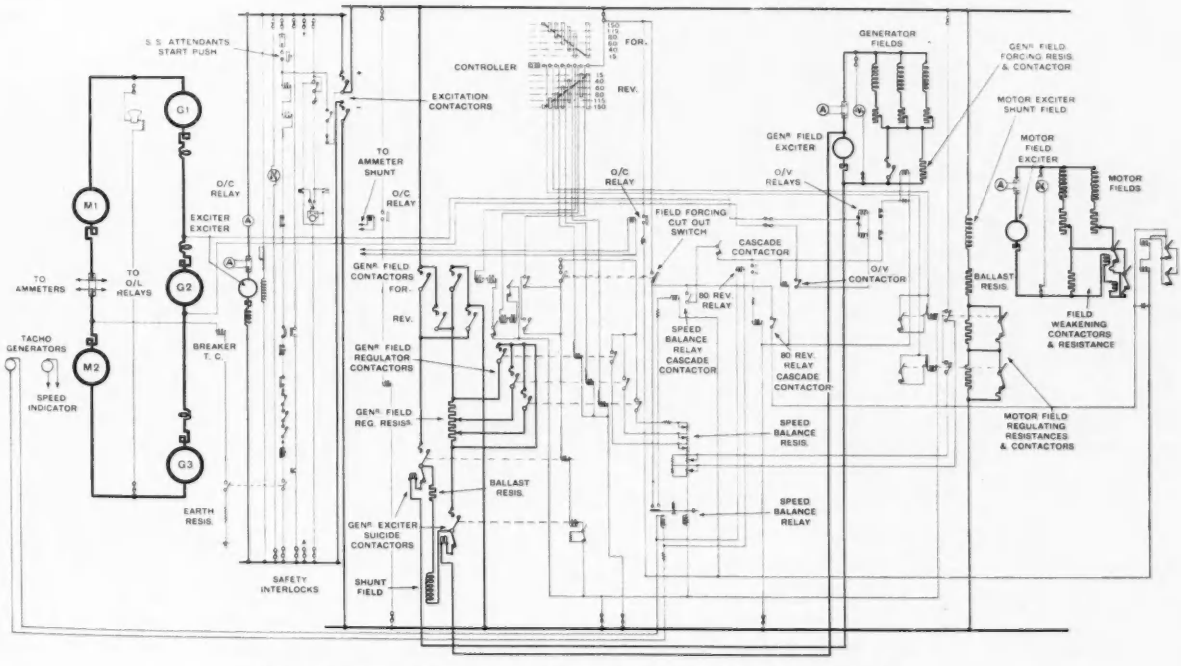


Fig. 10.—Arrangements of generator and mill motor circuits.

Ilgner Set.

The supply from the power station is at 2750 volts 3 phase 50 cycles. This is converted into direct current by means of the flywheel Ilgner set (fig. 7) previously mentioned. The generator side of this set consists of three 1580 kW generators connected permanently in series, capable of supplying the peak output of the mill motor. The drive is a 3,500 h.p. induction motor with a synchronous speed of 600 r.p.m. The supply to the motor is controlled from a 3-panel 11,000 volt truck cubicle switchboard (fig. 8). One panel controls the incoming supply from the power station, a second controls the supply to the Ilgner set, and a third feeds a 1,000 kVA 11,000/440 volt transformer supplying low tension current for mill auxiliaries.

In order to level out the power demand from the three-phase supply, a 40-ton flywheel is coupled to the motor generator set and has a kinetic energy at full speed of 175,000 h.p. seconds. The speed drop necessary to utilise the energy of the flywheel is provided by a slip regulator (fig. 9), connected to the sliprings of the induction motor. This regulator automatically inserts resistance into the rotor circuit as the load increases and is designed to limit the output of the motor to about 4,500 h.p.

The excitation of the Ilgner set is obtained from a separate motor generator set (shown in the foreground of fig. 8) consisting of a synchronous induction motor and exciter, an exciter for the generator fields, an exciter for the mill motor fields and a constant potential exciter for supplying excitation to the other exciters and various contactor coils.

Control Scheme.

In order to obtain the required output from the mill, it is essential that no time be wasted between one pass and the next. The rolls must therefore be reversed as quickly as possible after the billet has left them ready for the return pass. The field circuits of the generators and generator exciter are therefore designed for rapid magnetic response.

Several schemes of rapid response were considered and it was finally decided to use the simplest, although a slight reduction of permanent losses could have been obtained by the added complication of special field windings, additional contacts, etc. The scheme is briefly as follows. The speed range required from the mill motor is 60/0/60 r.p.m. obtained by varying the generator voltage, and 150/60/150 by shunt field control. Due to the shortness of the ingot in the early stages of rolling, rapid and frequent reversal is necessary, requiring the use of an easily operated controller if fatigue is to be avoided. The quick reversal of a machine by Ward-Leonard control implies a quick reduction to zero of the generator flux, immediately followed by its re-establishment. In this instance the required rapidity of reversal made "field forcing" necessary, both for the generators and the mill motor. The diagram fig. 10 shows how field forcing is applied. It will be seen that speed control and reversal of the mill are effected by a small master controller provided with six steps for either direction of rotation. As this controller merely energises contactors it is small in size and easily worked for long periods without fatigue.

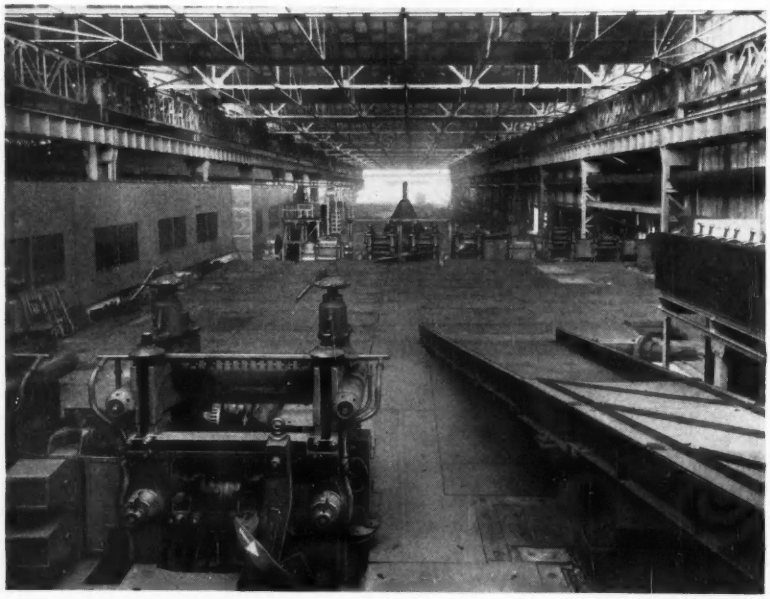


Fig. 11.—The new 14-inch merchant mill as seen from the roughing mill and looking towards the finishing mill.

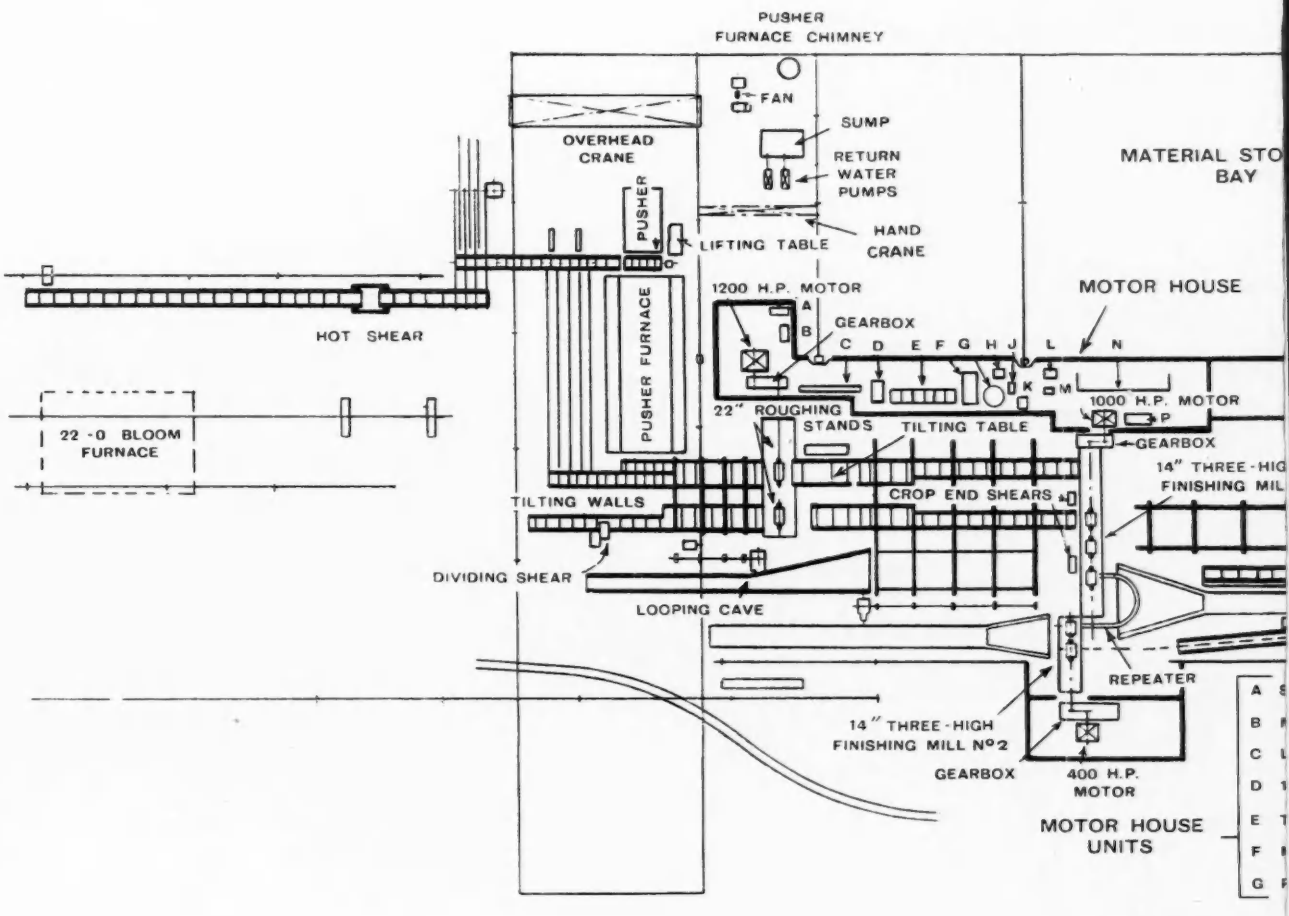


Fig. 12.—Layout o

ROLLING MILL EQUIPMENT FOR DORMAN, LONG & CO., LTD.

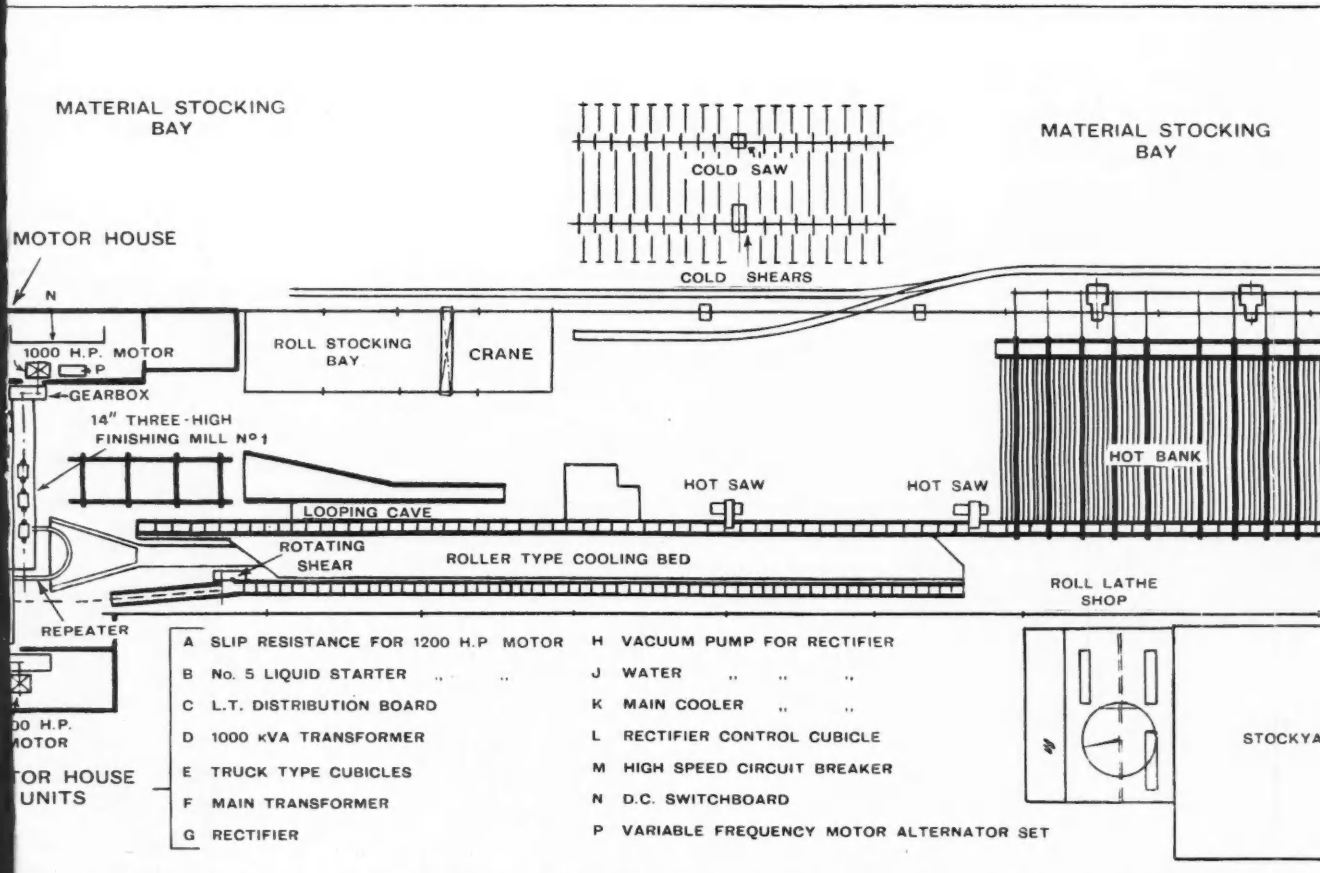
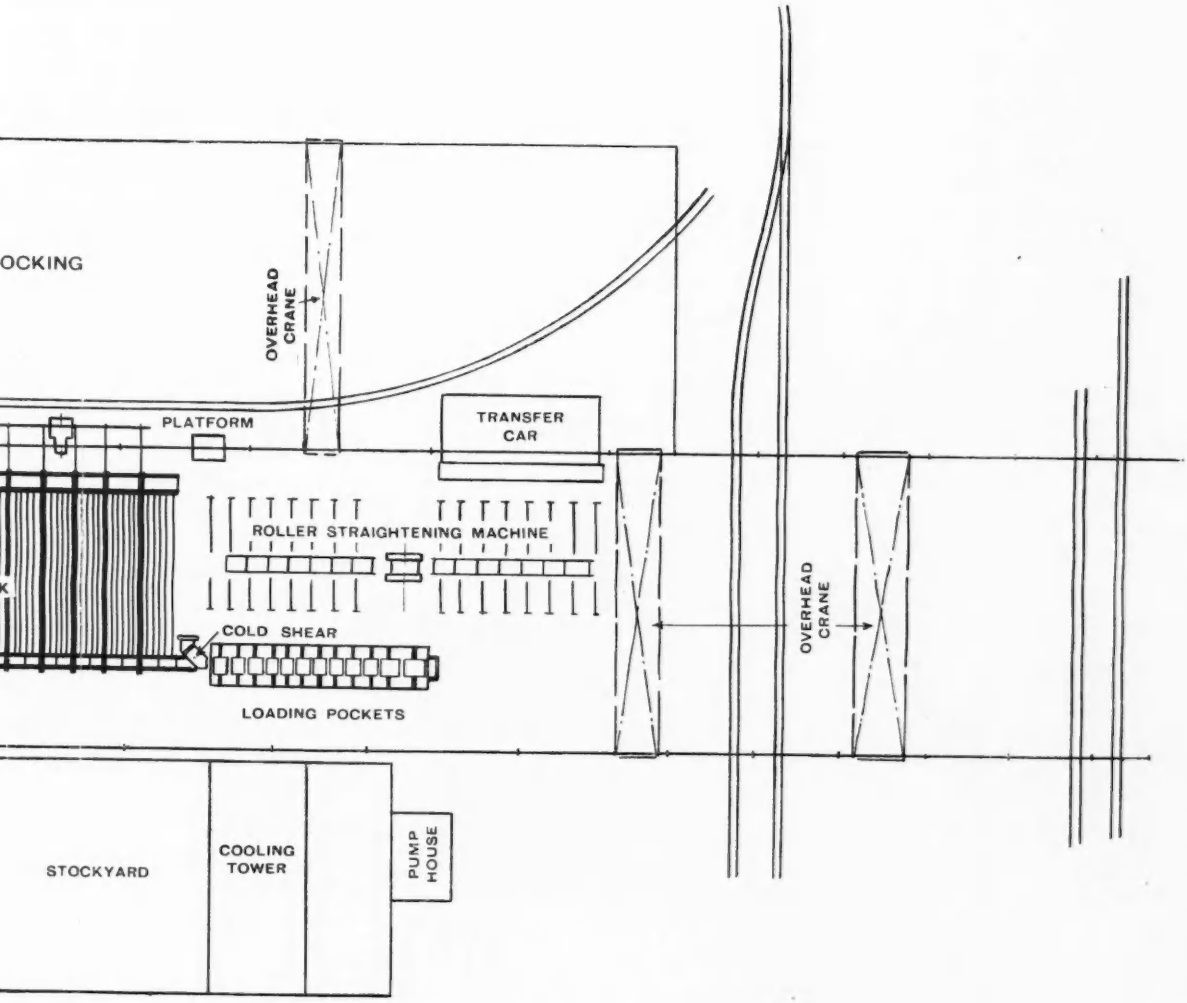


Fig. 12.—Layout of 14-inch Merchant Mill at the Cleveland Iron & Steelworks of Dorman, Long & Co., Ltd., Middlesbrough.


OCKING
OVERHEAD CRANE
PLATFORM
TRANSFER CAR
ROLLER STRAIGHTENING MACHINE
COLD SHEAR
LOADING POCKETS
OVERHEAD CRANE
STOCKYARD
COOLING TOWER
PUMP HOUSE

esbrough.

The contactors energised by the controller corresponding to the first three notches in either direction of rotation are arranged to increase the generator field current, giving stable speeds of 15, 40 and 60 r.p.m. respectively. The excitation is varied by adjusting the value of the generator exciter voltage. This exciter is peculiar to the generator fields and carries in its armature circuit a substantial resistance bank (known as the generator field forcing resistance) which can be short circuited by means of a contactor. The contactors energised by the final three notches of the controller reduce the motor field in two steps, corresponding to mill speeds of 80, 115 and 150 r.p.m. respectively. As in the case of the generators, the variation is effected by voltage control of an exciter peculiar to the motor fields, provided with a normally short circuited series resistance, known as the motor field forcing resistance. The rapid response of the mill to a reversal movement of the controller handle relies upon the control of the two field forcing resistances in the following way. Whenever the speed of the mill does not correspond to the speed position of the controller handle, field forcing is applied to the appropriate field. The operation of the field forcing gear is controlled by a speed balance relay of the beam type, which has two opposing coils, one energized from the line and one from the motor tachometer generator. The excitation of the line coil is derived from the exciter line and each notch of the controller adjusts this excitation to a certain predetermined value, closing the relay contacts and applying field forcing until the voltage (which is generated by the motor tachometer generator and is proportional to the speed) rises to a value sufficient to overcome the line coil. When this occurs, the field forcing conditions are terminated and the mill, having quickly changed speed or reversed, continues to run at the desired speed. In order to carry out speed change as far as possible with strong motor fields, a relay is employed to suspend motor field forcing until the speed has risen to 60 r.p.m.

It should be understood that if the field forcing contactors remained closed too long, the generators would soon reach over voltage, and to guard against this, duplicate over-voltage relays open the generator field forcing contactors. Similarly, failure to short circuit the motor field forcing resistances would damage the mill, and the short circuit contactors are therefore duplicated, while the speed balance relays act as an overspeed device. A separate exciter (part of the exciter set) supplies current at 220 volts for excitation and control purposes through a pair of excitation contactors, in the operating circuit of which are inserted all the usual operating devices, *i.e.*, "start" button (which is inoperative unless the controller is at the "stop" position), "stop" button, overcurrent relay, ventilating and lubricating oil interlocks, etc.

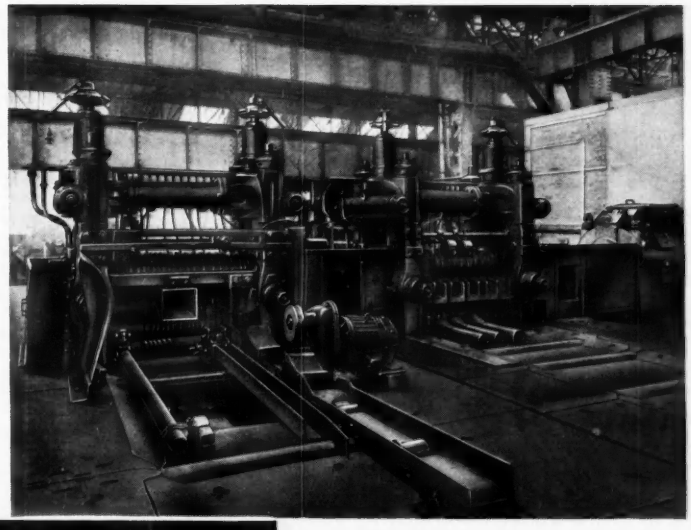


Fig. 14.—Rear view of the roughing mill.

Fig. 13.—Entry side of the 2-stand 3-high roughing mill driven by the 1,200 h.p. motor shown in fig. 22.

LIGHT SECTION MILL.

The new No. 8 light section mill (fig. 11) embodies the most modern developments in merchant mill practice. The general layout is illustrated in fig. 12.

Work was started on the construction of this mill in the spring of 1936, and the mill was started up in April, 1937. The plant was installed in an entirely new bay adjoining that originally serving an old three-high plate mill, and adjacent to the existing No. 6 steam driven cogging mill and reversing section mill. The general design and layout of the mill enables high outputs to be maintained, combined with good flexibility in respect of the types of sections rolled.

Fig. 15.—The 3-stand 3-high and the 2-stand 3-high finishing mills driven respectively by the D.C. motors shown in figs. 24 and 25.

Capacity and General Features.

The mill has a nominal output of 1,300 tons per week of a varied range of finished sections comprising the following :—

Joists, 3in. × 1½in.

Channels, 2½in. × 1in.

Angles, 2½in. × 2½in. to 1¼in. × 1¼in.

Flats, 3½in. to 1¼in. wide.

Squares, 1⅞in. to ½in.

Rounds, 2¼in. to ½in. diameter.

The roll stands are fitted with accessible chock adjustments and screwdown gear, and are designed to allow for rapid roll changing, a point of extreme importance in a mill of this type. The housing chocks incorporate fabric roll neck bearings fed under pressure by water from a separate supply system. The whole of the roller gear for the mill, including the approach bloom roller track, incorporates individually driven motor rollers, each externally driven by a flanged type motor.

The mill buildings consist of a cross bay 246ft. long by 50ft. span, housing the bloom feed banks and reheating furnace; also a new main longitudinal bay 780ft. long by 86ft. 6in. span with the original plate mill bay alongside for stocking and finishing purposes.

As will be seen from fig. 12, the mill consists essentially of two three-high roughing stands (figs. 13 and 14) followed by two finishing mills (fig. 15), the first of which comprises three stands and the second, two stands, the last stand of which discharges to a 200ft. long roller type cooling bed. An additional hot bank is provided for sections finishing in the third stand of the first finishing mill.

Feeding Arrangements.

Standard blooms 6in. square and 5 to 10ft. long are normally used and are supplied from the modernized No. 7 40in. cogging mill previously described and also direct from the adjacent No. 6 cogging mill. The blooms are transferred either into the bloom stocking bay or direct to the pusher type reheating furnace feeding the new mill.

This furnace, which incorporates a lifting table and hydraulic pusher gear at the entry end, is capable

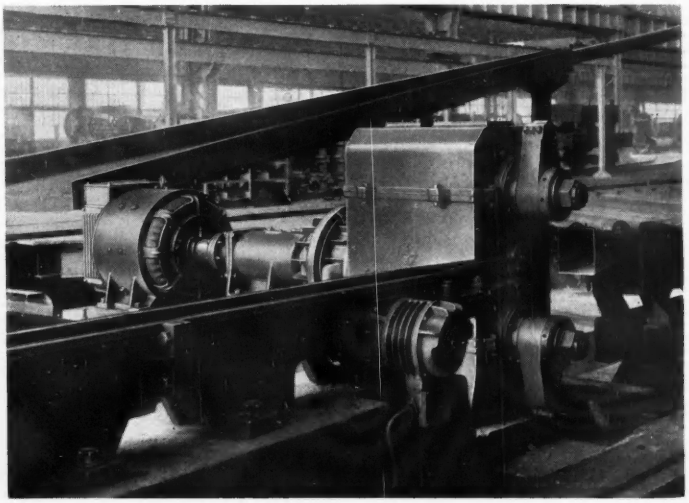


Fig. 16.—Automatic swing arm flying shear.

of accommodating a double row of 5ft. blooms and is fired with a mixture of coke oven and blast furnace gas. The heated blooms are despatched from the end of the furnace and are delivered automatically into the live roller track in front of the first roughing stand.

Roughing Mill.

The roughing mill embodies two three-high stands with rolls 22ins. diameter × 65ins. barrel length, and is typical of the modern type of mill with its automatic operation and high speed working. A front view of the mill is shown in fig. 13.

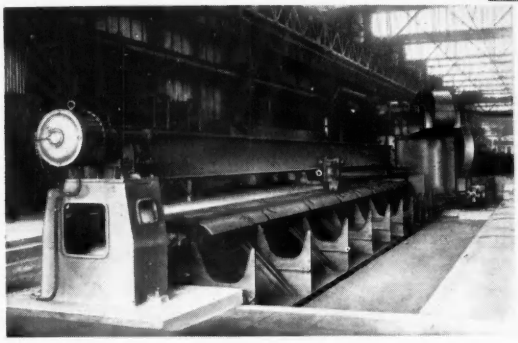


Fig. 17.—Cold shear for cutting rolled bars into merchant lengths.

The first stand is provided at the rear with a lifting table having a series of special trumpet turnover guides operated by the lifting action of the table. These guides receive the bar from the bottom pass and automatically bring it, by a combined lifting and rotating motion, to the necessary position for entering the top return pass. The bar is delivered automatically to the bottom passes at the front of the mill by means of fixed drop type automatic entry guides, or drop chutes. Behind the second stand is fitted a power driven tilting return trough, shown in fig. 14, and in front, a top-to-bottom repeater is used for the delivery of smaller sections to the final roughing pass. The pass design is such that the whole mill range of finished sections can be rolled without a change of roughing rolls.

The two roughing stands are driven through a reduction gearing by a 1,200 h.p. slipring induction motor housed in the main sub-station, giving a mill speed of 100 r.p.m. The motor shaft is provided with two flywheels.

Finishing Mills.

The 3-stand and 2-stand three-high finishing mills are each provided with rolls 14ins. diameter and 39⅜ins. barrel length, dummy rolls being used when only one pass per stand is necessary. Fig. 15

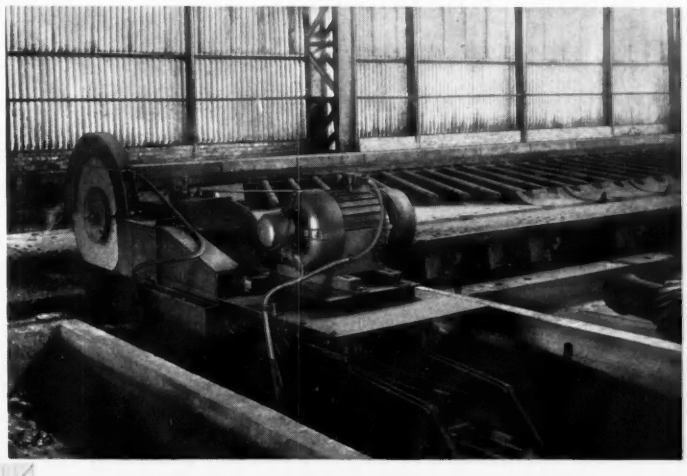


Fig. 18.—One of the two horizontal hot saws.

illustrates the general arrangement of this section of the mill.

The 3-stand mill is driven through a 4 to 1 reduction gearing by a 1,000 h.p. variable speed D.C. motor situated in the main substation. This drive gives a speed variation at the rolls of 125/250 r.p.m.

The 2-stand finishing mill is driven through a 2 to 1 double drive reduction gear by a 400 h.p. variable speed D.C. motor situated outside the mill bay. The motor gives a speed variation of 175/350 r.p.m. at the rolls. The 2-stand mill is slightly higher and offset to the 3-stand mill to enable the third stand of the latter to be driven separately from the 400 h.p. motor when the occasion demands.

The usual transverse finger skid gear is installed at the front and back of the 3-stand mill for handling the bars delivered from the roughing stand and, when necessary, between the passes.

When rolling rounds of ½in. to 1⅛in. diameter and squares ½in. to 1in. the five stands of the two mills are employed and automatic repeaters are used between the first and second, and third and fourth stands, and on certain sizes a double repeater is used to feed back from the second to the first stand. These repeaters, in conjunction with hand looping between the second and third, and fourth and fifth stands, sustain the continuity of operation and enable the last pass to be kept continuously filled at a finishing speed in the region of 1,000ft./minute.

The products from the fifth stand are received on the entry track of the mechanical cooling bank. The motor rollers on this track are driven by A.C. motors supplied from a variable frequency A.C. generator to give the necessary roller speed adjustment to suit that of the final finishing rolls.

The bar issuing from the final pass is automatically cut to pre-determined cooling bed lengths by means of an intermittent swing-arm type of flying shear, shown in fig. 16, which is electrically operated through

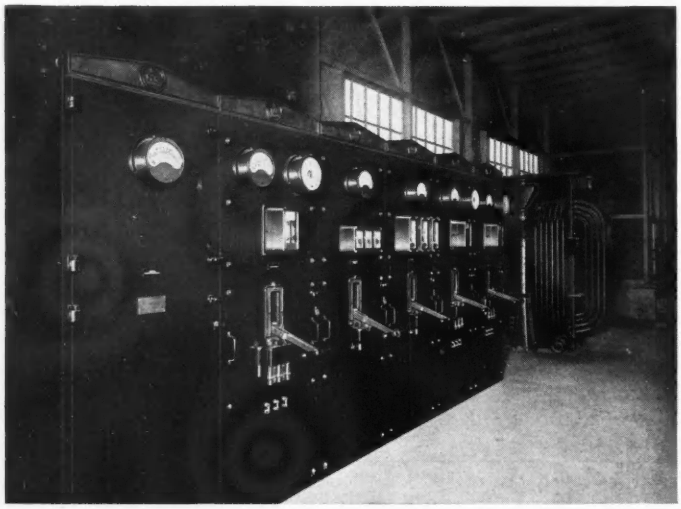


Fig. 19.—11,000 volt truck cubicle switchboard controlling incoming and outgoing supplies.

series relays from contact plates on the cooling bed receiving roller track. Bars are placed on to the diagonal roller type cooling bed, transversed and discharged in a perfectly straight condition in batches on to the runout roller track to the cold shear, the whole of these operations being performed semi-automatically.

Bars from the cooling bed are cut to length in multiples at the cold shear shown in fig. 17 and afterwards dropped into receiving pockets for bundling. They are then transferred by means of a special transfer carriage to the adjoining stocking and loading bay.

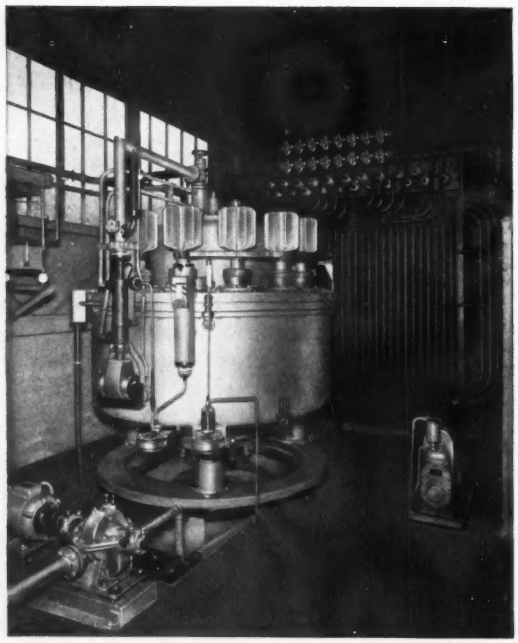


Fig. 20.—1,500 kW 500 volt 3,000 ampere water-cooled mercury arc rectifier. In the rear is the rectifier transformer.

The rolling of shaped sections finishes at the third stand of the 3-stand finishing mill. The bars leave this stand on the common outgoing roller track where they are cut to merchant lengths by means of two horizontal hot saws operating in conjunction with a quick acting stopper gear. One of these hot saws is shown in fig. 18. The bars are next cooled and batched on two 50ft. skid banks, after which they pass direct to a modern roller straightening machine. They are then transferred to the material stocking bay which is equipped with cold shears and a cold saw, and complementary benches for final finishing and ultimate loading.

It is worthy of note that all five stands of the finishing mills are equipped with interchangeable roll frames and spare housing caps to facilitate quick changing of the roll stands. By maintaining and setting up a spare set of frames with the necessary rolls, guide boxes, etc., the time required for roll changing has been reduced to a minimum and is approximately 45 minutes for the changing of all five stands.

The mill is also equipped with adequate roll stocking and crane handling facilities together with a modern roll lathe shop and high level control platforms for the mill operators.

A maximum weekly output of over 2,000 tons of mixed sections has so far been achieved on this mill. This is well in excess of the designed capacity and is a good indication of the flexibility and speedy working of the mill.

Electrical Equipment of the Merchant Mill.

The electrical equipment of the mill is of a particularly comprehensive nature, electricity being relied upon not only as a source of power, but also for the control of the extremely delicate operations necessary for the automatic working of the various units.

Power is taken at 11,000 volts from the works mains direct to a 6 panel high tension cubicle switchboard (fig. 19). This board controls the supply to (a) the 1,200 h.p. roughing mill motor; (b) a 1,500 kW transformer feeding a mercury arc rectifier which supplies direct current to the 1,000 h.p. and 400 volts mill motors, a variable frequency motor and a 100 h.p. D.C. roller straightener motor; and (c) 1,000 kVA transformer supplying the low tension A.C. equipment in the mill. The greater portion of the electrical equipment, including the 1,200 h.p. roughing mill motor, the 1,000 h.p. finishing mill motor, the rectifier and its associated equipment and main control switchgear are situated in the substation adjacent to the main mill bay.

Rectifier Equipment.

The mercury arc rectifier equipment which forms an important part of the scheme consists of the following :—

(*a*) E.H.T. switchgear.
(*b*) Main transformer.
(*c*) Rectifier.
(*d*) Rectifier control cubicles and auxiliaries.
(*e*) Reverse current high speed breaker.
(*f*) D.C. switchboard.

E.H.T. Switchgear and Transformer.

The rectifier oil circuit breaker is mounted in one of the 11,000 volt truck cubicle panels and consists of a hand-closed oil circuit breaker, the circuit of which is protected by three overload trips with inverse time limit characteristics. A further panel on the truck switchboard, which takes the form of a lockup cubicle, is fitted with isolating switches, E.H.T. "Quenchol" fuses and current limiting resistances controlling a circuit which supplies a small step-down transformer giving a 3 phase 230 volt supply for operating the various rectifier auxiliaries.

The main rectifier transformer (fig. 20) is of the indoor air-cooled type and is mounted adjacent to the rectifier. The primary is delta connected and the secondary has four 3-phase star-connected groups, arranged to give 12 anode connections to the rectifier.

Mercury Arc Rectifier.

The rectifier (fig. 20) is of the 12-anode water cooled type and is rated at 1,500 kW, 500 volts, 3,000 amps. with overloads of 25 per cent for 2 hours or 50 per cent for 15 minutes and 100 per cent momentarily. The rectifier is representative of the company's standard type for water cooled units and it is therefore only proposed briefly to describe its construction.

The main tank, which is cylindrical, forms the fundamental constructional unit of the rectifier and is surrounded by a main water jacket. The circular top plate is bolted to the main tank, and carries the main anodes, the auxiliary anodes and the condensing cylinder with its surrounding water jacket. The various units of the pumping equipment, *i.e.*, mercury vapour pump, interstage reservoir and barometric valve are secured to the top plate. On the top plate of the condensing cylinder is mounted the ignition solenoid, and the valve which connects the rectifier to the vacuum pumping equipment and gauges.

The main and auxiliary anode seals consist of a number of mild steel cones coated with vitreous enamel, and fused solid in an oven. The seals are thus exceptionally strong and have a very high dielectric strength, making perfectly vacuum tight joints when bolted to the top plate of the rectifier.

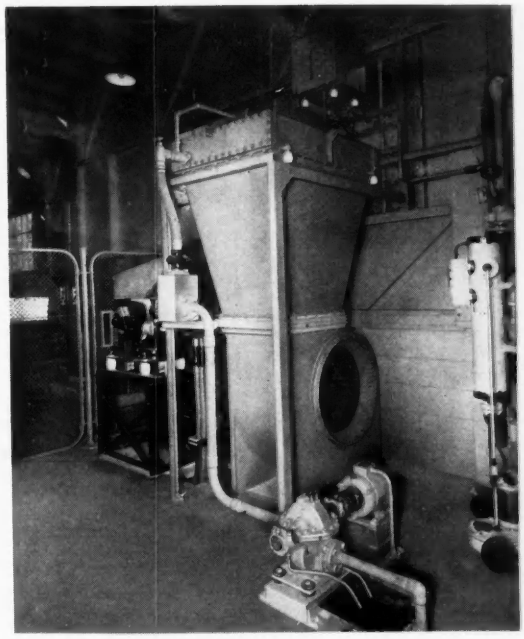


Fig. 21.—Rectifier cooling equipment and high speed circuit breaker.

The cooling system of both the rectifier and the mercury vapour vacuum pump is of the closed circuit circulating type (fig. 21), so that the rectifier is completely independent of any external water supply.

The operation of the rectifier is entirely automatic: the closing of the oil circuit breaker

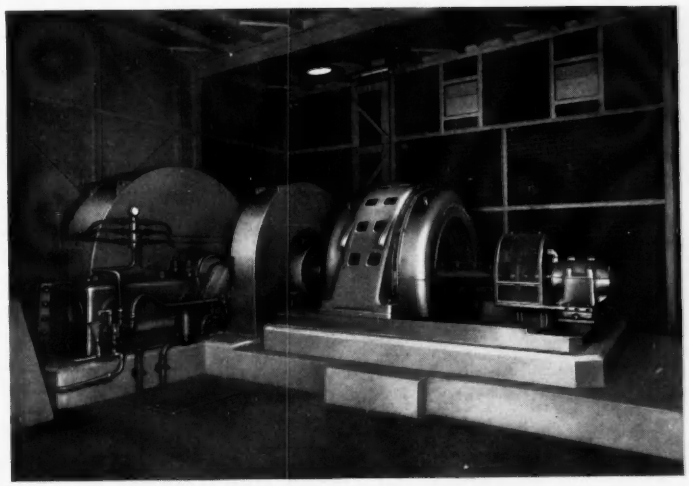


Fig. 22.—1,200 h.p. 11,000 volt slipring induction motor driving the roughing mill shown in figs. 13 and 14.

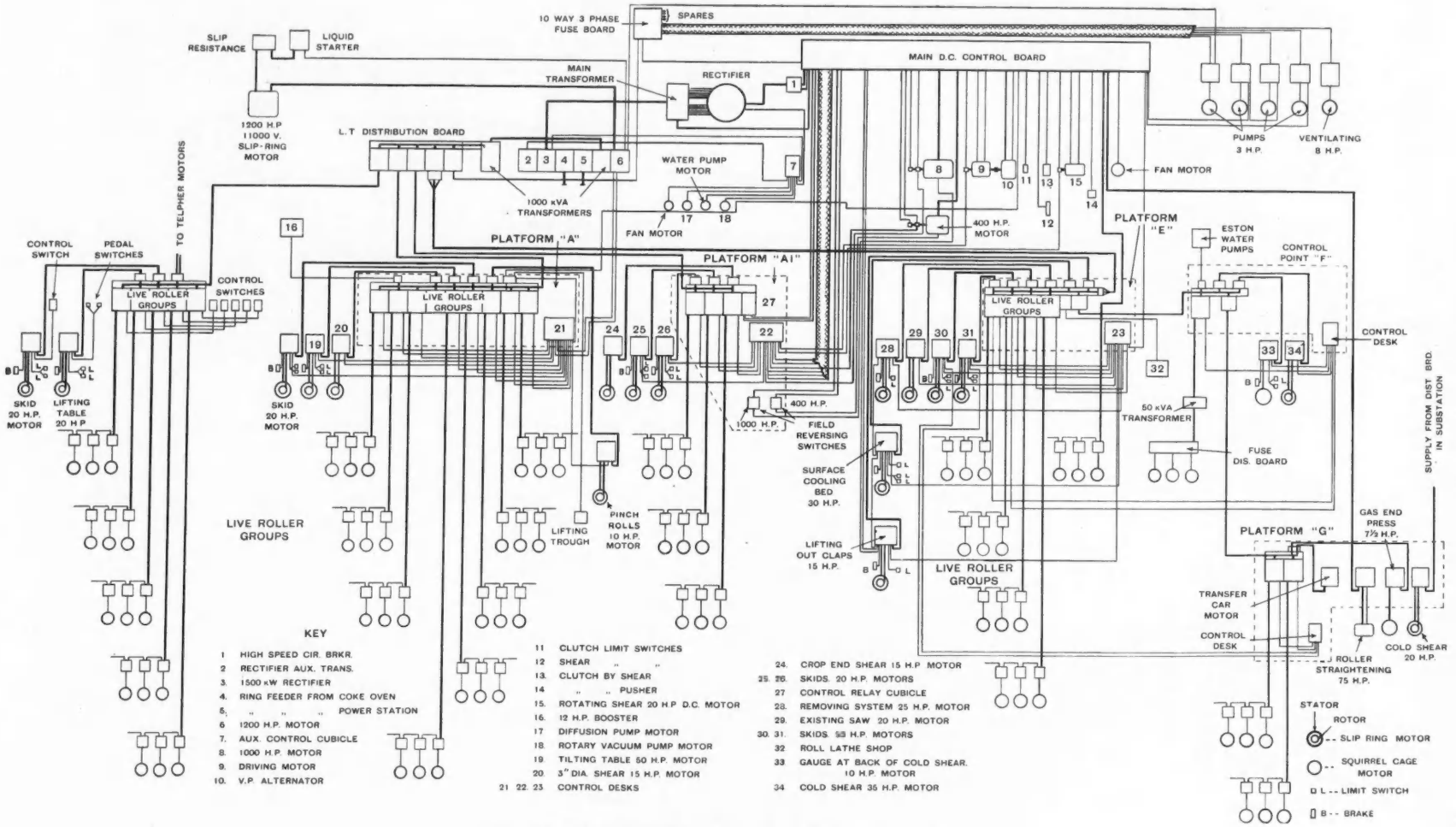


Fig. 23.—Circuit arrangements of 14-inch merchant mill.

initiates the arc in the rectifier and, as soon as the arc strikes, the rectifier is ready for load.

Rectifier Control Cubicle and Auxiliaries.

A sheet steel cubicle is provided to house all the relays, contactors, etc., required in connection with the automatic control of ignition, vacuum pumps, cooling pumps and fans and the auxiliary anode circuit.

This equipment provides for the automatic control of ignition, excitation circuit, circulating water pump and cooling fan, after the starting sequence has been initiated by the closing of the rectifier oil circuit breaker.

Mounted within the enclosure containing the rectifier plant is a reverse current high speed circuit breaker (fig. 21), connected in the positive D.C. lead from the cathode to the D.C. switchboard. This breaker is push-button controlled from the D.C. switchboard. In the negative lead a hand operated overload circuit breaker of normal pattern is installed on the main D.C. switchboard.

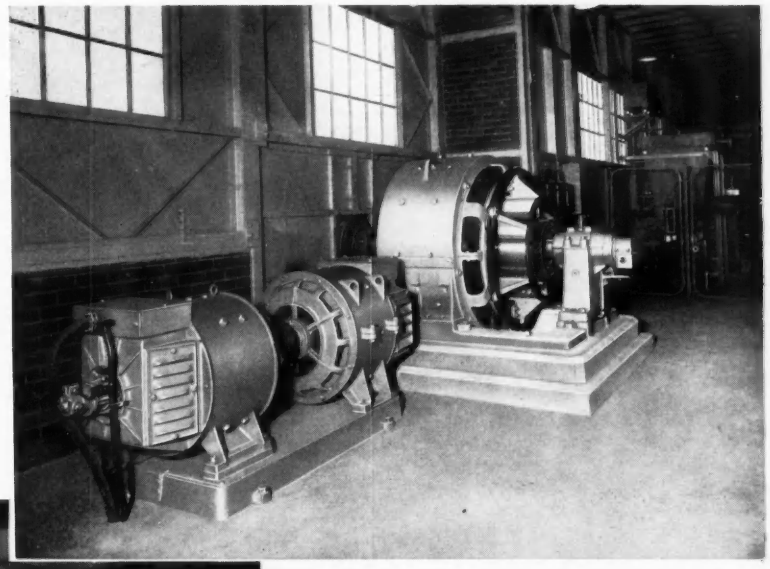


Fig. 24—1000 h.p. 500 volt 480/960 r.p.m. D.C. motor driving the 3-stand finishing mill; in the foreground is a variable frequency generator set.

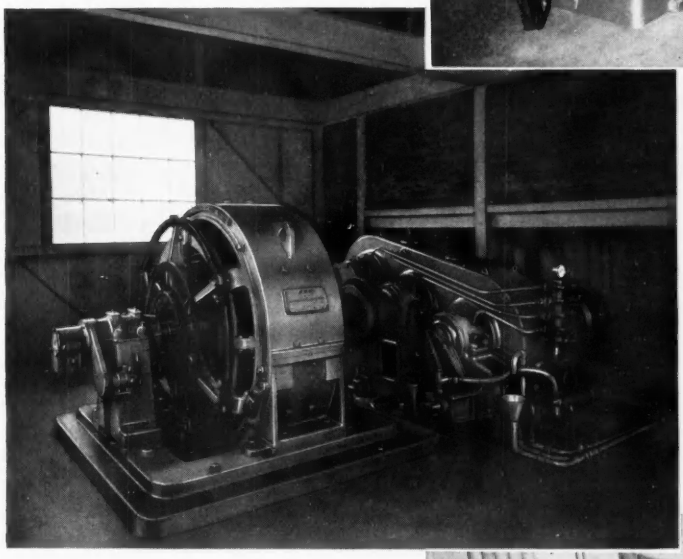


Fig. 25.—400 h.p. 500 volt D.C. motor driving the 2-stand finishing mill.

Protection.

Protective features are provided to ensure that possible damage due to system faults or to faults on the rectifier plant itself is reduced to a minimum, and include E.H.T. overload protection, D.C. overload protection, overload protection on all auxiliary motor circuits for operating fans, pumps, etc., excessive temperature of rectifier top plate, and vacuum failure. Tension limiters

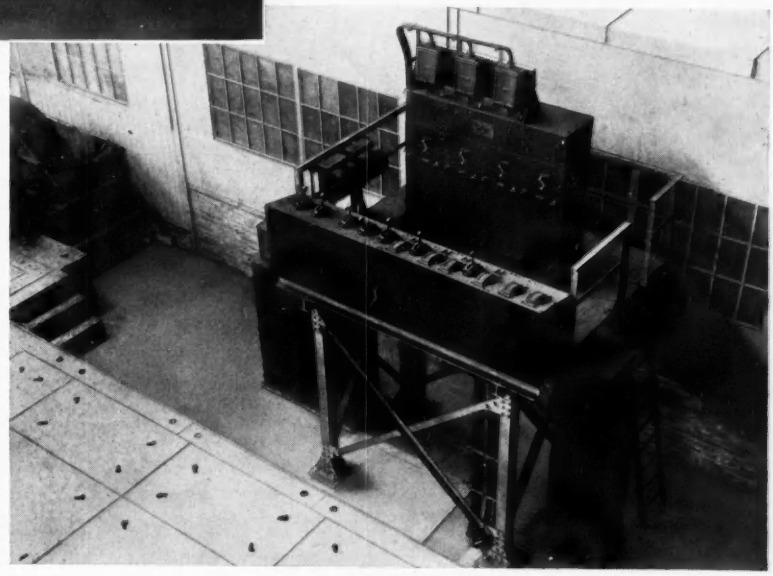


Fig. 26.—One of the pulpits from which the finishing mill is controlled.

Fig. 27.—D.C. switchboard controlling finishing mill motors and auxiliary D.C. circuits.

are also provided on the main and isolating transformer secondaries to protect the windings against any surges which may be induced due to arc instability on heavy overloads or during other abnormal conditions.

Roughing and Finishing Mill Motors.

Although reference has already been made to the mill motors it will be of interest to give certain further details.

The 1,200 h.p. roughing mill motor, fig. 22, is of the standard induction type and calls for no particular comment except that the design and construction of the machine are such that the heavy overloads encountered in rolling mill practice can be handled with safety. With this motor are associated a liquid starter and air cooled resistances of the cast grid type.

The 1,000 h.p. and 400 h.p. D.C. motors driving the 3-stand and 2-stand finishing mills respectively are of the open type and are shunt wound, fitted with light stabilising windings, compensating and interpole windings. The full rated output of each machine is given at any speed over its range. Excitation is obtained from a separate motor generator set. Views of the 1,000 h.p. and 400 h.p. D.C. motors are shown in figs. 24 and 25 respectively.

Motor Control Equipment.

For the control of the two D.C. rolling mill motors a main D.C. switchboard is installed and is shown together with the 1,000 h.p. motor in fig. 27. A diagram of connections for the complete control scheme of the mill is shown in fig. 23.

Associated with the main D.C. switchboard are a number of control pulpits situated at various points in the mill from which the operators can obtain a clear view of the equipment under their control. One of these pulpits is shown in fig. 26. The control desks on these pulpits carry lever operated master controllers, adjusting regulators and push-buttons, controlling the various mill motors and auxiliaries. The switchgear, through which the control pulpits operate, is mounted (in the case of D.C. motors) on the D.C. switchboard and (in the case of the A.C. motors) on a 5-panel low tension A.C. switchboard. Of the five panels comprising this board the first supplies "Sub-distribution board No. 1" which deals with live rolls, skids, and lifting tables on the incoming side of the furnace. The second panel feeds "Sub-distribution board No. 2" on control platform A, which control a further 8 groups of live rolls, skids, tilting tables, etc., in connection with the roughing mill. The 1,200 h.p. motor driving this mill is also controlled from Platform A. The third panel on the low tension A.C. board feeds the sub-distribution board on Platform A1 which controls three live roll groups, two skids and one crop end shear. The 1,000 h.p. and 400 h.p. finishing mill motors are also operated from this platform. The fourth, fifth and sixth panels of the low tension board feeds sub-distribution boards on further control platforms dealing with live rolls, skids, etc., in connection with the cooling beds, saws, shears, etc.

As regards the control of the two D.C. motors which is carried out from platform A1, the control switchgear mounted on the desk operates in association with the main D.C. switchboard (fig. 27), to which a 500 volt 3 wire D.C. supply is fed from the mercury arc rectifier. On the incoming panel of this board a double-pole hand-operated circuit breaker of the line contactor type is mounted.

The panels controlling the rolling mill motors are similar and on each are mounted a double-pole hand-operated line contact circuit breaker, the necessary accelerating contactors, field protective relays and counter-E.M.F. relay. On the panels for the 1,000 h.p. and the 400 h.p. motors the last step of the resistance is cut out by a solenoid operated single-pole line contactor circuit breaker. In all cases the circuit breakers are equipped with overload and under-voltage trips. Those controlling the 1,000 h.p. motor are rated at 1,600 amps. while the breakers for the 400 h.p. motor will carry 800 amps. Eleven accelerating contactors are supplied for the larger

motor and seven for the smaller machine. These are operated from the control platform.

For normal starting conditions the controller is moved on the pulpit to the first notch which provides creeping speed. In the event of the mill being "stiff," a condition likely to occur after a prolonged shut down, the controller is moved to its third notch which provides full load torque on the motor. Provision is also made for the shunt regulators to be left in position so as to give the correct motor speed for any particular rolling operation. For this purpose, vibrating contactor field relays are mounted on the main switchboard so that when the motors are re-started they automatically attain the correct speed as determined by the positions of the appropriate shunt regulators.

In order to prevent over-voltage at the rectifier when slowing down either mill motor, and also to permit of a certain amount of electrical braking, a suitable resistance is connected across the rectifier by means of a relay and absorbs power from the motor side.

Full protection is provided to safeguard the motors against (1) excessive speed due to failure of the field circuit and (2) flashover due to restoration of full field when the motor is running at high speed. In the event of a complete break in the field system the motor is automatically stopped, but should a partial failure occur with corresponding weakening of the field the protective relays safeguard the motors against excessive speed and stop the mill. Protection against flashover as a result of full field being restored to the motor while it is still running at high speed is provided by a counter-E.M.F. relay which ensures that the shunt field resistance remains in circuit until the back E.M.F. of the motor has fallen to a pre-determined value. Without this relay, any rapid movement of the controller to the "off" position would result in full field being restored on the motor before it had time to lose its speed which is maintained for a definite time by the inertia of the machine.

Auxiliary Drives.

Motors and control gear have also been installed for the operation of many auxiliaries in the mill. Examples of these are illustrated in figs. 16, 17 and 18. They include a 100 h.p. D.C. motor driving a roller straightening machine. This motor is fed from the rectifier and is controlled by a contactor starter under remote or push-button control. Other auxiliary drives include motor drives for the furnace lifting table, approach rolls, tilting tables, etc.

Fluorescent Tube Lighting.

The Committee Room in the new Corporation Electricity Showrooms at Bridlington, illuminated by " Osira " fluorescent tubing concealed in a cornice to give indirect lighting.

Colour and Colour Rendering.

By CLIFFORD C. PATERSON, O.B.E., D.Sc., M.Inst.C.E., M.I.E.E.,
Director of the Research Laboratories of The General Electric Co., Ltd., Wembley, England.

This is a verbatim report of the Presidential Address delivered by Dr. Paterson to the Institute of Physics on the occasion of the Third Conference on Industrial Physics held at Leeds on March 23rd, 1939.

The speaker informed his audience that a limit had already been reached in the yield of light from incandescent solids, while gaseous sources of light still offered possibilities of extensive development.

The main problems associated with gaseous light concerned the control of its colour rendering properties.

Experiments were performed to show the differences in the colour rendering properties of various forms of daylight, and the importance of arriving at a standard of artificial daylight.

A description of trichromatic colorimetric systems was given with particular reference to the C.I.E. system. Finally the speaker discussed the use of fluorescent materials with discharge lamps, illustrating his remarks with numerous demonstrations.

YOU technicians in the textile or colour industries have, I think, accustomed industry to look upon colour mainly as an attribute of an object. You dye the fabrics you give us, or paint surfaces with colours which, when illuminated with so-called white light, give hues which you can predict with fair accuracy and can define in terms of recognized colour charts.

And those of us who made the light which illuminated your coloured surfaces used to play the game and give a reasonably white variety of light. But we have recently had to ask you to probe more deeply into the nature of this light and its effect on your colours. So long as both the electrical engineer and the gas engineer produced their light by the incandescence of solids, your colours responded with reasonable consistency to the stimulation of this white light radiation. At least the reproducibility was not less consistent than that afforded by the rather variable hues with which the Almighty presents us in ordinary daylight. True it used to be rather tame—knowing exactly what everything and everyone would normally look like—though some thought there was a restfulness about it which was not to be undervalued.

Nevertheless, for good or ill, a change has come. When research workers in the electrical field learnt, a few years ago, the way to make practical light sources by passing electricity through gases and vapours, they could not ignore the relatively enormous yields of light so obtainable for the electricity consumed. A limit in the yield of light from incandescent solids had already been reached, and here were gaseous sources of electric light giving upwards of three times the amount of light for the same electricity costs!

The unusual and varied colour of the light from these very efficient sources was startling, but from the beginning we always felt that research would find ways of modifying and controlling these colours. The first objective aimed at was to exploit the possibilities of high efficiency. But the appraisement and the modulation of the colour of the light has followed quickly, and the subject of my discourse this afternoon is the examination of some of the considerations which arise in the production and use of coloured sources of light.

The so-called colour of a source and the colour rendering which it gives to objects illuminated need to be carefully distinguished—as all, in fact, know who have studied the art of critical colour matching.

Most of us, I imagine, are inclined to think of electric discharge sources as emitting light of a few isolated wavelengths and, in consequence, being quite unsuited for work involving the accurate discrimination of colours. If we do, we are forgetting one discharge lamp which is unique in having colour rendering properties probably more nearly perfect than those of any other artificial source. This is the carbon dioxide lamp. Here is a photograph of the visible spectrum of this lamp (fig. 1). The closely packed banded spectrum has an energy distribution very close to that of average north daylight.

At the other extreme there is the sodium lamp of

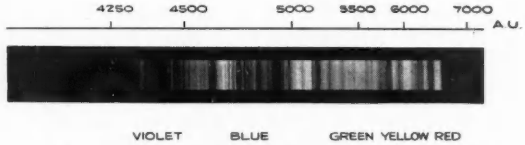


Fig. 1.—Spectrum of carbon dioxide daylight lamp.

which the colour rendering is so distorted that it may almost be taken as non-existent.

In spite of the poor efficiency of carbon dioxide lamps (it is about one-twentieth of that of our newest sources of light) they are finding increasing

use in industry for critical colour appraisement. They have the great advantage over daylight in giving a constant colour and intensity, and also their light is available for 24 hours of the day.

Before going on to discuss the colour rendering properties of other forms of discharge lamps and the methods which have been developed to improve these, I should like to say something about the characteristics of light sources which depend on temperature radiation and then to discuss the important question of the measurement of colour.

Firstly, with regard to natural daylight—

LIGHT SOURCES—NATURAL AND ARTIFICIAL.

(*a*) *Daylight.*

The eye having evolved under daylight conditions, it is only natural that we should form our judgment of other illuminants with respect to daylight, from the point of view of intensity levels, colour and colour rendering properties.

But daylight is of necessity very variable, it changes both in colour and intensity with time of day and season, weather conditions and aspect. Direct sunlight being radiation from an incandescent body approximates to radiation from a black body, at least in the region of visible radiation. Actually, the colour temperature of sunlight can vary from something in the region of 2,000 degrees K. at sunset, to about 5,500 degrees K. at midday. The equivalent colour temperature of radiation which is a mixture of sunlight and light from a clear blue sky is in the region of 7,000 degrees K. as also is that from an overcast sky, whereas that from blue sky alone can vary from 12,000 to 25,000 degrees K. As daylight may be any (or a mixture) of these various approximations to black body radiation, it is not surprising that its intensity and colour rendering properties are extremely variable and that it is not the most suitable reference standard of light under which to attempt to discriminate or measure the "colour" of materials. The extent of these differences in daylight and their effect on the colour rendering properties are rather forcibly brought home to us by this demonstration.

Here we are illuminating a white opal glass screen by artificial daylight in some of its many forms. The adjacent vertical strips are illuminated by light similar in colour temperature to that of daylight, ranging from the "reddest" form on the extreme left (which can occur with direct sunlight at sunset), to the "bluest" form normally used for colour matching, on the extreme right, namely that from an overcast sky.

If we now hold in front of the white screen a series of horizontal strips of coloured gelatine, it appears at once how different are the colour rendering properties of daylight in its various forms.

Of course, we are deceived into thinking of daylight as possessing constant colour rendering properties because the differences which may occur are seldom contrasted.

The variability of the intensity of daylight has not a very direct bearing on the question of colour rendering, but it is interesting on account of its great range, which may be seen from this typical daylight record taken at the National Physical Laboratory (fig. 2).

Average Daylight.

But we have to get to an anchorage somewhere amidst all this variability, and to try to agree arbitrarily

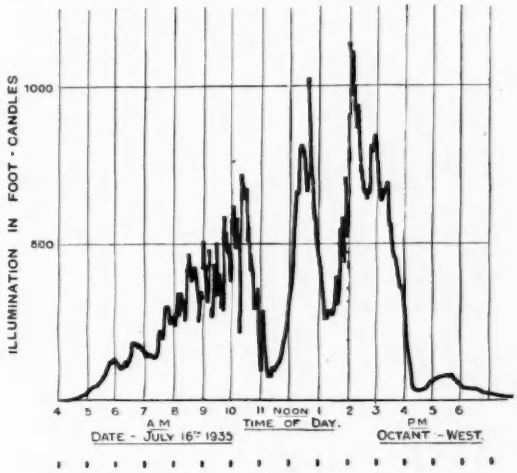


Fig. 2.—Typical daylight record taken at the National Physical Laboratory.

what shall be taken as average daylight, and what standard shall represent it. The day is passing when "north sky light" is an acceptable standard for comparing the "colour" of fabrics and the like. Even north sky light is variable, and the number of useful hours in the working day during which it can be used in Leeds, for example, amounts during the winter to only about 4 hours per day. Hence the value of artificial daylight illuminants for colour matching, the choice of the most suitable depending on the task to be performed.

As I shall remind you in a later section of this lecture, an internationally agreed colorimetric system[1] has been evolved, together with standard illuminants for use in calibrating colorimeters in terms of this system.

Standard illuminant A is a tungsten filament lamp operating at a colour temperature of 2,850 degrees K.

Standard illuminant B is derived from illuminant A in conjunction with a Davis-Gibson liquid filter, and the transmitted light has a black body colour temperature of 4,800 degrees K. (one of the redder phases of daylight).

Standard illuminant C is derived from illuminant A in conjunction with another Davis-Gibson filter,

and in this case the transmitted light has a black body colour temperature of 6,500 degrees K. (one of the bluer phases of daylight).

But there is no internationally agreed artificial daylight for use in colour matching.

Whilst this position may be satisfactory from the colorimetric standpoint, it is *not* satisfactory for the technique of appraising colour rendering properties. For this purpose we want a definition for average daylight so that we may have a usable standard of artificial daylight. As we now have established means of defining colour it would seem but a small step to fix upon one or other of the black body colour temperature levels as representing average daylight. If one of the bluer phases of daylight were chosen, for example, that from an overcast north sky corresponding to a black body colour temperature in the region 7,000 to 8,000 degrees K., this would tally very closely with light from a CO_2 Daylight Lamp.

(*b*) *Artificial Illuminants : Temperature Radiators.*

It is interesting to glance at earlier forms of artificial illuminants to see how they compare with daylight from the colour rendering point of view. My next slide (fig. 3) gives a list of the more common

Type of light source	Approximate black body colour temp.
Candle	1800°K
Paraffin lamp	
Coal gas flame	
Acetylene flame	2300 to 2400°K
Carbon filament electric lamp ..	2000K
Tungsten filament electric lamp (vacuum)	2300 to 2400°K
Tungsten filament electric lamp (gasfilled)	2500 to 3300°K

Fig. 3.—Approximate colour temperature of the light emitted by different sources.

temperature radiators arranged in chronological order, together with their approximate colour temperatures. You see how progress had led to the adoption of light sources of increasing colour temperature, but that the colour temperature of the hottest tungsten filament falls considerably short of that of "average daylight." This will be better appreciated by reference to this demonstration which is very similar to that* in which we compared the colour and colour rendering properties of the different forms of daylight. It is rather interesting to note how the colour temperatures of these artificial illuminants overlap daylight in its lower colour temperature forms, and the extent of the difference in colour rendering properties.

The colour temperature at which tungsten filament lamps can be operated is determined by the design of lamp and the life which is considered satisfactory, so that in the case of the photographic type of lamp, for example, where a two-hour life can be tolerated, the colour temperature is in the region of 3,400 degrees K. As the melting point of tungsten is no higher than 3,650 degrees K., it becomes necessary to associate colour filters with such filaments (either in the form of blue glass bulbs or in suitable lamp fittings) if we wish to utilize tungsten lamps for producing artificial daylight.

Such an arrangement forms a very convenient source of artificial daylight suitable for any purposes where extreme constancy of colour is not of fundamental importance. Its efficiency is about the same as that of a carbon dioxide lamp. Unlike the latter, however, the colour is a function of the supply voltage, which may vary by as much as ± 6 per cent in many districts.

And now a word on the measurement of colour.

MEASUREMENT OF COLOUR.

(*a*) *Trichromatic colorimetric systems.*

There is such an immediate and pressing demand for simple techniques for measuring and specifying both the colour and colour rendering properties of light sources, that we are likely to see a number of new proposals put forward in the near future.

In a desire to remain loyal to the internationally agreed system,[2] we should naturally turn to this system for a solution of our problems, and I think that we shall see that it does not fail us. I would like to remind you of some of the properties of trichromatic systems before proceeding to consider the application to our problems, and I hope the experts will forgive me for considering this problem from first principles in an endeavour to show, among other things, that the internationally agreed system is really very simple and convenient in practice.

Now we are all familiar with the fact that light of any colour, including "white," can be produced by a mixture of light from three primary sources, a primary source being one which cannot be produced by a mixture of the other two. The more saturated the primary (*i.e.*, the closer they are to spectral colours) the larger will be the range of colours which can be matched by suitable mixtures of these primaries.

We are now mixing red, green and blue monochromatic light and producing white light on this translucent screen. As you will see, the result matches the white light on the adjacent portion of the translucent screen which is illuminated by a tungsten filament daylight lamp. Of course, you will not all agree that these two are exactly the same colour because of the differences in the colour sensitivity of individual eyes. It is important to note that although the colour of the light in these two cases is the same, the spectral energy and luminosity distribution are quite different, as shown in these two diagrams (fig. 4). For this reason the colour

* The demonstration described above on p. 173.

rendering properties will be very different, as you will see if we hold in turn in front of these two fields a number of colour filters.

We will now repeat this experiment, but this time

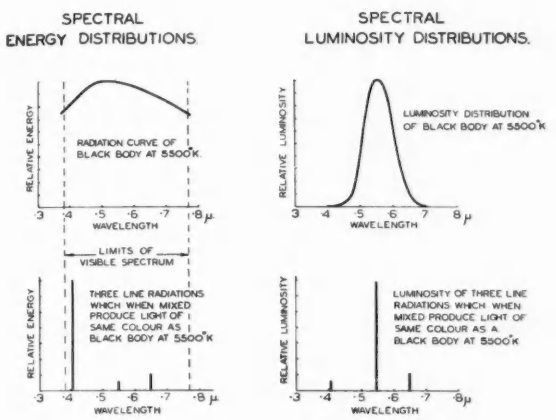

SPECTRAL ENERGY DISTRIBUTIONS
SPECTRAL LUMINOSITY DISTRIBUTIONS.
RELATIVE ENERGY
RADIATION CURVE OF BLACK BODY AT 5500°K.
WAVELENGTH
LIMITS OF VISIBLE SPECTRUM
THREE LINE RADIATIONS WHICH WHEN MIXED PRODUCE LIGHT OF SAME COLOUR AS A BLACK BODY AT 5500°K
RELATIVE LUMINOSITY
LUMINOSITY DISTRIBUTION OF BLACK BODY AT 5500°K
LUMINOSITY OF THREE LINE RADIATIONS WHICH WHEN MIXED PRODUCE LIGHT OF SAME COLOUR AS A BLACK BODY AT 5500°K

Fig. 4.—Spectral energy and luminosity distributions.

we will put a colour filter in front of the tungsten lamp and match this light by mixing different proportions of the three monochromatic primaries. Again you see how different are the colour rendering properties.

A colour can thus be defined by stating the proportions of the mixtures of primaries required to produce a colour match with the unknown coloured source. This can be expressed in numerical form in the manner shown on the screen (fig. 5). Similarly the luminosity can be expressed by the addition of the

FORM OF NUMERICAL EXPRESSION FOR SPECIFYING ANY COLOUR.

(COLOUR) $S = \alpha R + \beta G + \gamma B$

where (including negative values) $\alpha + \beta + \gamma = 1.0$

(WHITE) $S_w = 1/3R + 1/3G + 1/3B.$

LUMINOSITY OF COLOURED SOURCE.

$$L_s S = \alpha L_r R + \beta L_g G + \gamma L_b B$$

$$L_s = \alpha L_r + \beta L_g + \gamma L_b$$

Fig. 5.—Colour Equations.

luminosity coefficients. But much more is needed in its definition, if its colour rendering properties are to be appraised.

The conventional manner of plotting these colorimetric co-ordinates is in a Maxwell triangle as shown in the left hand diagram of my next slide (fig. 6); or on rectilinear co-ordinates, as shown in the right hand diagram where only two co-ordinates are plotted.

With any three *real* primaries, even if they are monochromatic, and consequently of 100 per cent saturation, there will be some colours which can only be matched with a mixture involving negative co-ordinates. That is, in order to obtain a match in a colorimeter it will be necessary to mix with the test source light from one of the primaries. If the spectral colours (100 per cent saturation) are plotted on the Maxwell triangle such colours will be located outside the triangle on the spectral locus. However, all colours which can be matched by positive or negative mixtures of these primaries will fall within the figure formed by the spectral locus and the line joining the ends of the spectral locus. In this form of diagram the plotted positions of the complementary colours are joined by straight lines through the "white" point.

But, in addition to the "primary colour" method just described, any colour can also be matched against a suitably proportioned mixture of a spectral colour plus "white" light, or in the case of the magenta colours, "white" light minus a spectral colour. For example, again making use of this colour-mixing apparatus, we will this time match our coloured light source by selecting monochromatic light from the spectrum and mixing with it a suitable proportion of white light.

Now, it is a property of the Maxwell triangle that, not only does a plotted colour point in the triangle indicate the proportions of the three primaries which when mixed will match light of a particular colour, but it also indicates that an appropriate mixture of a particular spectral colour and "white" light will match the colour, already defined in trichromatic units. The two methods, which have just been demonstrated, of obtaining a mixture to colour match our source under test are therefore simultaneously indicated on the diagram.

In this triangle, a line has been drawn from the

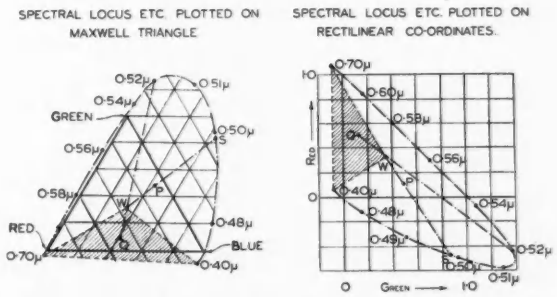


Fig. 6.—Trichromatic system with real red, green and blue monochromatic primaries.

white point through the colour point plotted at *P*. The hue wavelength of this colour is indicated by the intersection of the line with the spectral locus at *S*, while the saturation, or proportion of spectral to white light, is indicated by the ratio of the lengths of the line *PW* to *WS*. Any colour lying within the area bounded by the dotted line can be treated in

this manner. However, the magenta colours indicated in the shaded area within the triangle are *not* spectral colours, but can be matched by white light *minus* the requisite proportion of light of a hue wavelength indicated by the intersection of the line from

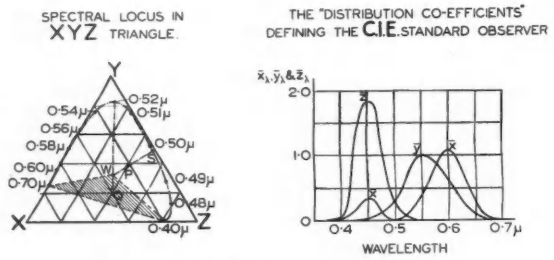


Fig. 7.—C.I.E. trichromatic system.

Q through *W* to the spectral locus.

So far we have only talked about one particular trichromatic system, having convenient real primaries. But as you will remember, it is possible to use any convenient three primaries chosen from the large number of real primaries available and to consider the trichromatic mixtures in the respective systems. Actually, in practice, for the reasons already stated, visual trichromatic colorimeters are used having different sets of real primaries, involving negative values in the colour co-ordinates.

It was in order to meet this situation that the system was devised which was internationally agreed in 1931. Unfortunately, in the limited time available it will only be possible to make brief reference to the system adopted by the Comité International d'Eclairage.

In addition to possessing all the

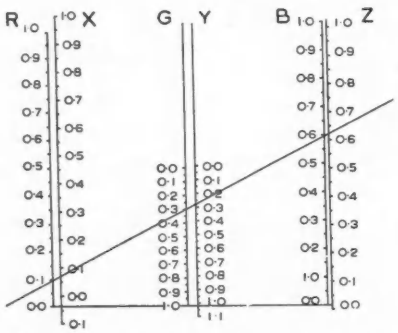


Fig. 8.—Nomogram for converting R.G.B. co-ordinates of photoelectric colorimeter to XYZ co-ordinates of C.I.E. system.

characteristic properties associated with trichromatic systems having real primaries (to which I have already referred), as you will see from this slide (fig. 7), the spectral locus on the C.I.E. system is everywhere within the triangle so that the trichromatic coefficients of all colours are positive. The primaries in this case are imaginary.

In the right hand diagram on this slide are plotted the distribution coefficients used in indirect colorimetry for calculating the trichromatic co-ordinates from the spectral energy distribution of a source.

The relation between colorimetric systems using real primaries, and the C.I.E. system, is a linear one so that the transformation from one system to another is not difficult, and in practice for most purposes sufficient accuracy can be obtained by using nomograms of the form shown in fig. 8. Thus the conversion

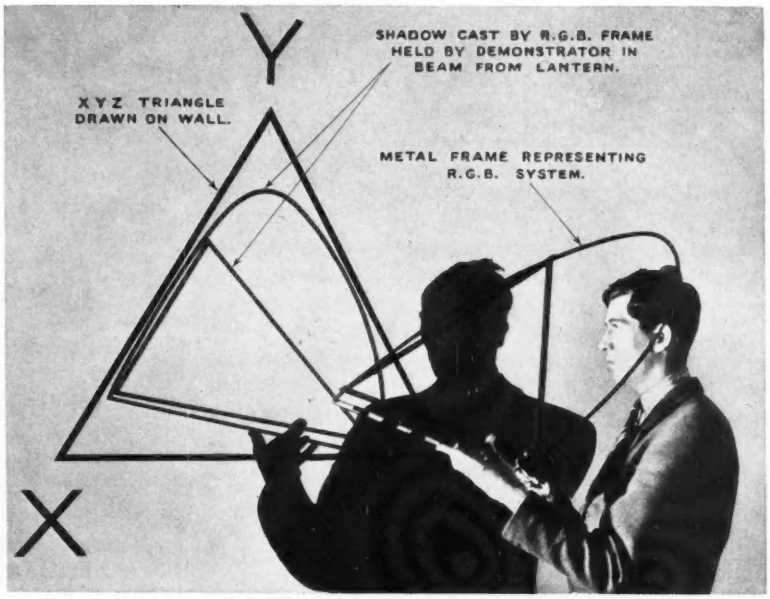

Y
X
SHADOW CAST BY R.G.B. FRAME HELD BY DEMONSTRATOR IN BEAM FROM LANTERN.
XYZ TRIANGLE DRAWN ON WALL.
METAL FRAME REPRESENTING R.G.B. SYSTEM.

Fig. 9.—Demonstration illustrating how trichrometric systems having different primaries are related to one another.

to the international system can be accomplished in a matter of seconds.

Perhaps this demonstration (fig. 9) will better illustrate how these trichromatic systems, having different primaries, are related to one another.

Here we have two frames representing the trichromatic system already shown in an earlier slide, plotted on trilinear and rectilinear co-ordinates respectively. If we hold these in turn in the beam of this projector, I think you will readily appreciate how these systems are plane projections of one another, with the fixed points on the spectral locus common to all of them.

(b) Colorimeters.

Now we have seen how the *colour* of the light can readily be specified on the C.I.E. trichromatic

system, but the types of visual colorimeter obtainable on which such measurements can be made are generally unsuitable for making rapid routine determinations, as they require skilled observers to operate them.

A much simpler and more rapid technique has recently been evolved for indicating, to industrial accuracies, the colour of the light from a source. This is an experimental photoelectric colorimeter,[2] which consists of three rectifier type photocells covered with suitable colour filters and connected respectively to three galvanometers (fig. 10). By an appropriate optical system the galvanometers project line images so arranged that, with the galvanometers at zero, these line images form an equilateral triangle (fig. 11). The light which is to be analysed for colour, falling uniformly on the three photocell components, causes deflections of the three galvanometers, and movement of the three lines towards the centre of the triangle. By adjusting the total amount of light falling on the cells there is one position where the three lines must intersect at one point, which therefore represents directly the location of the colour of the light source under test within this particular trichromatic system.

Thus we have a ready means of measuring the colour, but not the colour rendering properties, of a light source. But we also want to know how to appraise the appearance of coloured articles and materials, that is, the colour of the reflected light, which will naturally vary radically with different illuminants.

The colour rendering properties of a light source will depend on its spectral energy distribution. This may be different for light sources of the same colour, that is, having the same trichromatic co-ordinates.

For example, if we illuminate one half of a white screen by light from an H.P. mercury lamp, and the other half by light from a tungsten source in front of which is a filter (actually of daylight-blue type glass), the two adjacent surfaces appear approximately the same colour. However, the colour rendering properties of these two light sources are very different, as will be appreciated when pieces of coloured gelatine filter are held in front of these surfaces.

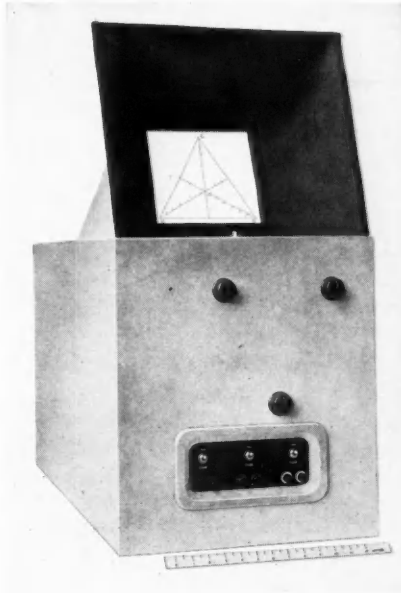


Fig. 10.—Three-galvanometer colorimeter.

Already many methods have been suggested, either based on measurements of relative energy or luminosity in various spectral bands, or on the visual judgment of the apparent colour of coloured materials, etc., when viewed under the various light sources. These methods have their uses, but are rather laborious.

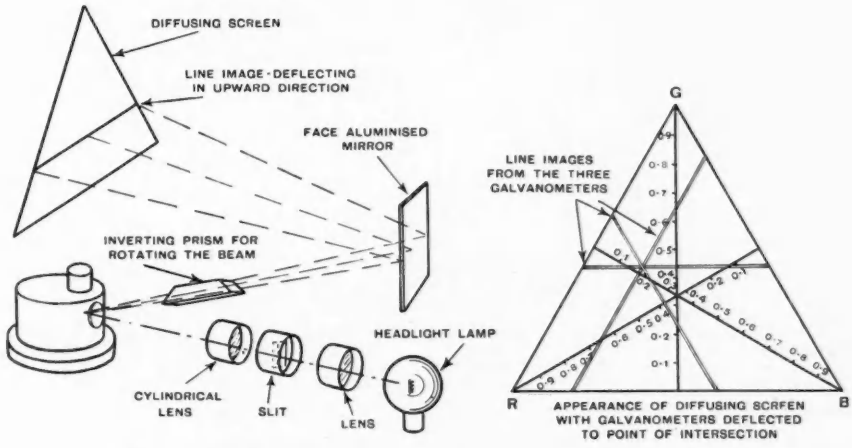


Fig. 11.—Optical arrangement of one galvanometer system.

Having, in the photoelectric colorimeter referred to earlier, a very quick method of measuring colour, why should we not make use of this to measure the colour-rendering properties? For example, if we determine the colour of the light source, and also the colour of the light reflected from, or transmitted through, a suitably selected group of coloured materials, or filters, the relative position of these points in the colour triangle should enable not only the colour, but the colour-rendering properties resulting from the particular form of spectral distribution of the source, to be determined. It will be obvious that in this case two sources which appear the same colour, but are different in spectral distribution, will be differentiated by the values of the trichromatic co-ordinates of the reflected or transmitted light from, or through, the coloured media.

I should like now to consider from the colour rendering point of view the newer types of sources to which I referred in my opening remarks—the electric discharge in gases and vapours.

DISCHARGE LAMPS.

In the case of the electric discharge in gases, we are no longer under the restriction imposed on temperature radiators, that the colour rendering of the source is a function of the operating temperature. The possibility that a high proportion of the input energy be radiated in the visible region of the spectrum is now open. Of course, as we shall see later, this does not necessarily, or even generally, mean that such gaseous sources have good colour rendering properties. But it does mean that much higher luminous efficiencies are possible than is the case with temperature radiators. This point is one of the utmost importance where light has to be employed in any quantity, and we shall see how far it is possible to fill in the gaps in the spectrum of discharge sources and so improve the colour rendering.

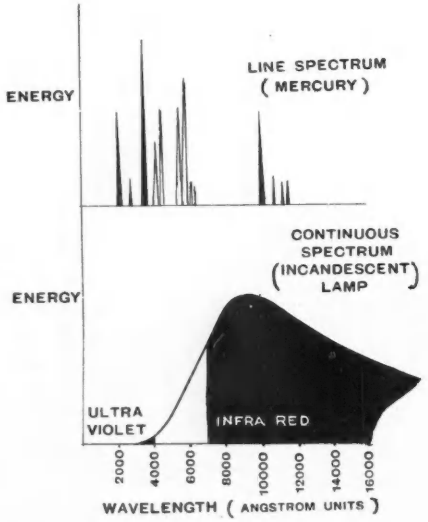


Fig. 12.—Energy distribution in continuous and line spectra (not to same vertical scale).

Let us look at this diagram (fig. 12) which shows the radiation emitted by a hot tungsten filament. The top diagram shows the same thing for the mercury vapour discharge. In each case the parts outlined represent the light we get, while the black areas to the right of the diagram represent the energy which is emitted as heat, and those to the left of the diagram represent the ultra-violet radiation. We shall see later how the latter may be transformed into useful light. But we see from the relative amounts of black on the two diagrams what a lot of useful radiation we get from the mercury in proportion to the amount which is wasted as heat.

The next slide (fig. 13) shows the efficiencies of a number of different sources.

Let us suppose that all the electrical energy absorbed by a lamp could be converted into light of the colour to which the eye is most sensitive. The

LUMINOUS EFFICIENCY VALUES.

All the energy radiated at wavelength 5500 A.U. (green) } 620 Lumens/watt

PRACTICAL TUNGSTEN FILAMENT LAMPS	
	Lumens/watt
15W. and 25W. vacuum	8–9
40W. to 1500W. gas filled	10–20
Special projector types	26

PRACTICAL DISCHARGE LAMPS	
	Lumens/watt
400W. High pressure mercury vapour lamp	45
100W. Sodium lamp	70
150W. Neon floodlighting lamp	10
50W. High voltage tubes (various types)	5–60

Fig. 13.—Efficiencies of various sources.

luminous efficiency would be 620 lumens per watt, but the light would be bright green in colour and not at all suitable for general illumination. You will see from this slide how far the efficiencies of practical lamps are below this theoretical maximum. The highest of them, the sodium lamp, is only about one-tenth of the theoretical.

These lamps all work on the same principle, that is, the electricity, instead of heating a wire to incandescence, is made to pass through certain gases or vapours. That is to say, the gas in the tube, or enclosed envelope, absorbs energy during collisions with ions moving in the electric field set up by the applied voltage, and emits the energy as radiation, which, unlike that from a temperature radiator, is made up of a number of discrete wavelengths.

Let us compare once again the colour rendering of sodium and carbon dioxide light. The sodium

lamp is one of the most efficient we have, but unfortunately we don't yet know of a good way to improve its colour rendering properties. We saw a few minutes ago that mercury radiates red, blue and green spectral lines. Let us now illuminate the fabrics with mercury light instead of sodium, still using the carbon-dioxide lamp as a standard. You will note that under mercury light the yellows and greens are accentuated while the reds scarcely show up at all. Mercury light gives a distorted colour rendering, but unlike sodium, shows strong colour contrasts. Neon gas, as you know, radiates mainly red and orange light and is almost completely deficient in green and blue rays. Let us compare the fabrics under neon and CO_2 light. Under neon light the green and blue fabrics look black, while red and orange colours look almost white by comparison.

Mercury, sodium and neon are of particular interest because these are the only gases or vapours which, so far, have really been put to practical use for general illumination purposes. Why is this? The reason is not far to seek. There is one overriding gauge of usefulness, namely, efficiency: the amount of light a source will yield for the energy taken to operate it. The filament lamp sets a standard, and if, in competition with the filament lamp, discharge lamps are to make an appeal to the public for general lighting, and particularly to that section of the public which is technically or commercially interested in colour rendering, it is clear that they must not only be much more efficient (which, in fact, they are) but must be made to give light which renders the colour of objects with reasonable accuracy and which is flattering to the complexion.

This brings me to the latest refinement which the physicist has applied to the perfection of these lamps—the use of fluorescent materials.

Before discussing this important application, I would like to devote a little of my time to a consideration of the subject of fluorescence.[3]

It is well-known that when ultra-violet radiation falls on certain substances these are sometimes seen to glow with a characteristic colour. In other words, there is a transformation of invisible ultra-violet radiation into visible light and the substance is said to be fluorescent. Sometimes the substance continues to glow even after the ultra-violet radiation is shut off. This is called phosphorescence.

The phenomenon is by no means a recent discovery. There is a Chinese record of about 980 A.D., in which mention is made of a luminous pigment prepared from calcined oyster shells.

In 1852, Stokes, working in Cambridge, discovered the fundamental law of luminescence, which states that the fluorescent radiation must be of longer wavelength than that of the exciting radiation. This simply means that it is possible to excite red fluorescence by blue light but impossible to excite blue fluorescence by red light. A convenient method of demonstrating fluorescence experiments is to use a source of ultra-violet radiation from which all visible light has been filtered by means of a special glass screen containing a few per cent of nickel oxide. Here is such an ultra-violet lamp which comprises a quartz high pressure mercury vapour lamp in a nickel glass bulb (fig. 14). This is rated at 125 watts and forms a highly efficient source of near ultra-violet radiation. Shown alongside it is a similar clear bulb lamp for comparison.

I have two of these black glass lamps burning inside the box, on the left hand side of the bench. Under such lamps as these nearly all objects fluoresce to some extent. As you can see, the hands, and particularly the teeth, show up quite well under the radiation from these lamps. On the other hand metal objects, which do not show fluorescence, are scarcely visible under these lamps. Thus, here is a sheet of aluminium which can only be seen with difficulty in ultra-violet light, while these chemical compounds, when prepared in special ways, show very strong fluorescence. It is with these substances I propose, now, to deal.

Here are a number of cards coated with various fluorescent sulphides.

(*The lecturer showed a blue fluorescing card which was coated with zinc sulphide, activated with* 1 *part in* 10,000 *of silver. The same substance exhibited green fluorescence when activated by* 1 *part in* 20,000 *of copper.*

It was shown that the addition of cadmium moved the fluorescent colour towards red, also that a very good white can be obtained by a mixture of fluorescent materials.

A highly phosphorescent card was also shown).

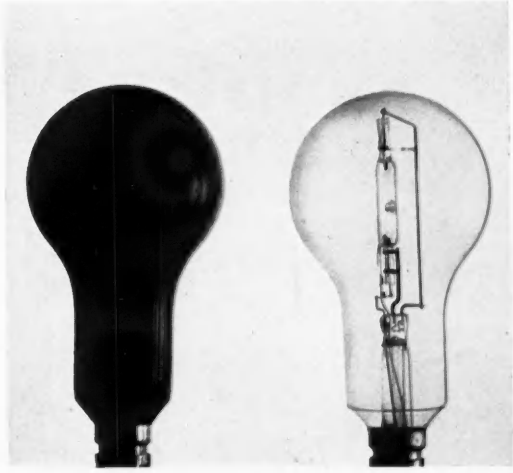


Fig. 14.—(left). A high pressure mercury vapour ultra-violet lamp in a nickel glass bulb and (right) a similar lamp in a clear bulb.

All these materials belong to what is known as the sulphide class. Their outstanding characteristic is that they are strongly excited by long wavelength ultra-violet radiation and even by visible light. There is, however, another very important class of fluorescent material which requires shorter wave ultra-violet radiation as an exciting agent. The silicates and tungstates belong to this class. These materials are of the greatest importance from the point of view of discharge lamps.

One of the methods employed for the study of the effectiveness of different regions of the spectrum for exciting fluorescence is to allow a known ultra-violet spectrum, such as the mercury spectrum, to fall on the powder coated on a card or plate.

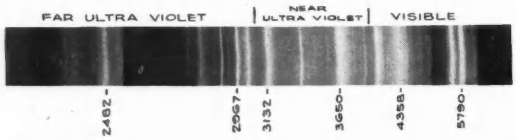


Fig. 15.—Spectrum of high intensity mercury discharge lamp.

In order to demonstrate this method to you I have had the spectrum of a very intense mercury vapour discharge source projected onto the small screen (fig. 15).

At the moment, all that you can see on the small screen on the lecture bench is the visible spectrum which is crushed up into a band of coloured light a few inches wide. The ultra-violet spectrum extends between this and the end of the screen, and if a card coated with a sulphide powder is placed in the beam, the ultra-violet spectrum appears by fluorescence.

(*The lecturer showed that if a card coated with a silicate in place of the sulphide is used, the spectrum is extended further into the ultra-violet towards the left-hand end of the screen.*

Bringing forward a card coated with tungstate which fluoresces blue, the lecturer demonstrated that the introduction of a sheet of glass into the beam from the mercury lamp served to absorb the short wave ultra-violet rays and thus to cut off the excitation from this cause. By means of a phosphorescent screen it was possible to obtain an afterglowing record of the spectrum).

It will be clear from all this that any discharge lamp which radiates an appreciable portion of its energy in the blue or ultra-violet regions is capable of exciting one or other of these compounds to emit visible light. The fluorescent light mixes with the direct light from the discharge to give a resultant light of a different colour and usually of a higher efficiency.

Let us refer to our colour energy distribution diagram again (fig. 12). You will notice once more the powerful ultra-violet lines emitted by the mercury discharge and represented by the black lines on the left of the diagram. It is these lines which are so useful in exciting fluorescent substances. Here is a similar diagram for the sodium discharge (fig. 16). You will see that practically all the energy in the sodium lamp is given out as two very strong lines in the yellow. This explains why sodium has such a high luminous efficiency. It also explains why sodium is not much good for exciting fluorescence, since there is practically no ultra-violet radiation given out. There is thus little or no possibility of correcting the colour of sodium by means of fluorescence.

The two main classes of fluorescent material we have been discussing—the sulphides and the silicates—each has its own special use in discharge lamps. In high pressure mercury vapour lamps where the operating temperature is much too high to permit of powders being applied to the walls of the discharge envelope, the powder is applied as a thin uniform layer to the inside surface of an outer jacket. In the high pressure lamps the ultra-violet radiation given out is mostly of the long wave type which excites the sulphides and not the silicates. For this reason only partial correction of high pressure lamps is obtained. However, the improvement is considerable and sufficient for nearly all industrial purposes. I have an experiment here to demonstrate the degree of correction obtained.

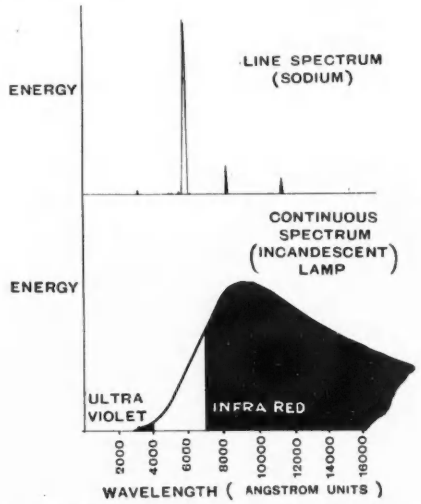


Fig. 16.—Energy distribution in continuous and line spectra (not to same vertical scale).

(*The lecturer displayed two* 125W. *quartz high pressure mercury vapour lamps, one in an ordinary bulb and the other having an outer bulb coated with fluorescent powder. This converted the ultra-violet radiation into light of the colour in which the lamp was deficient, thus giving improved colour rendering without any loss in efficiency.*

One or two lengths of coloured fabrics being placed under the lamps, it was seen that the reds in particular were greatly improved. An assistant then held his

hands beneath the lamps to demonstrate the extent to which the colour of the skin was improved).

Fluorescent lamps rated at 80 and 125 watts have just recently come on the market, although a 400 watt fluorescent lamp has been marketed for about two years. These lamps are, or course, only meant to give a moderate degree of colour rendering which is all that is required for many industrial processes.

Now in the case of the low pressure mercury vapour discharge, of which the blue and green tubes used in advertising are examples, the temperature of the discharge is low enough to permit the powder to be used inside the discharge envelope and in direct contact with the discharge. Furthermore, in the low pressure discharge there is a high proportion of short-wave ultra-violet radiation emitted which is capable of exciting the highly efficient silicate type powders. The possibility of greatly improving the colour and the efficiency of the low pressure discharge is thus open to us. Here is a low pressure mercury tube, one half of which is coated internally with a green fluorescing silicate. The other half displays the mercury discharge without the addition of fluorescence. Each half is, of course, using the same amount of energy, but you will observe that the light output of the coated half is greatly enhanced. The increase is actually some eight or ten times with this particular powder. Under suitable conditions it is possible to excite fluorescence by the neon discharge, and neon filled fluorescent tubes are playing an increasingly important part both in advertising and interior lighting.[4]

Here is a neon filled fluorescent tube coated with green and blue fluorescent powders to give yellow and pink resultant colours. The section of the tube on your right is uncoated to show the pure neon discharge for comparison. The candle-power maintenance of these neon filled fluorescent tubes is extraordinarily good, the light output remaining constant for thousands of hours.

Here are a number of tubes showing the wide range of colours which is possible. For purely decorative work it is, of course, attractive to have as many colours as possible from which to choose. None of the tubes you see here is suitable for discriminating colours accurately, or even approximately, when used alone. By combining the light from certain of these coloured tubes, however, a resultant mixture is obtained suitable for general interior lighting, and even for work involving colour discrimination such as the lighting of shops.

Fig. 17.—Installation of fluorescent tube lighting in the author's office.

My next slide (fig. 17), shows an installation of fluorescent tube lighting in my office at Wembley. And here (fig. 18) is an installation in the gauge standards room of an aeroplane factory. These long tubular sources give excellent light distribution and

Fig. 18.—Fluorescent tubes give the necessary high intensity evenly diffused lighting in the gauge room of an aeroplane factory.

form very attractive lighting units. Considerable progress has been made in the development of luminescent powders which give a colour suitable for general interior lighting from a single tube without having to resort to mixing the light from tubes of different colours.

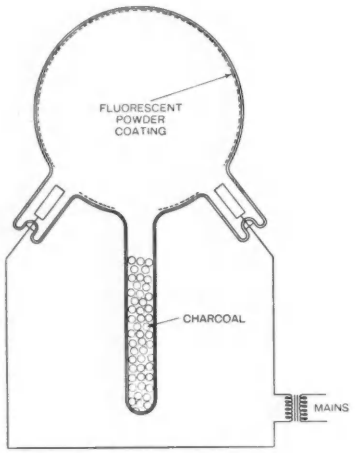


Fig. 19.—Diagram of electronic lamp.

(*The lecturer called attention to some white tubes giving a light similar to daylight at an efficiency of about* 30 *lumens/watt. Each tube consumed only about* 50 *watts and required high voltage for its operation. It was apparent that they gave quite good colour rendering.*

Some samples of 25 *watt fluorescent tubes of comparable efficiency, and designed to operate at normal supply voltages, were also exhibited*).

I should like, finally, to show you another method of producing light from fluorescent materials. This is by electronic excitation. Here is what might be described as an electronic discharge lamp coated internally with a green fluorescing powder (fig. 19). It is filled with a couple of millimetres of pure argon which can be pumped out by immersing the charcoal side-tube in liquid air.

If we pass current through the lamp the glow is barely perceptible. There is no electronic excitation of the powder because the electrons in the discharge are prevented by the gas atoms from reaching the coating on the walls. Let us absorb the gas by cooling the charcoal in liquid air. As the pressure falls, the distance the electrons can move without being interfered with by molecules of gas increases, until they are able to strike the fluorescent powder on the walls with increasing force. The powder is then seen to be excited to a brilliant fluorescence which stops, you will notice, as soon as the gas pressure falls so low that no more electrons are present. If the charcoal is heated again by removing the liquid air, the gas molecules reappear and the sequence of happenings takes place in the reverse order.

In the time at my disposal this afternoon I have tried to indicate some of the problems associated with the colour rendering properties of artificial sources—particularly electric discharge lamps—and to give you some idea of the important part which luminescent materials have already played in the improvement of the colour rendering properties of these lamps. There can be little doubt that the phenomena of fluorescence and phosphorescence will play an increasingly important part in the future development of these highly efficient sources.

REFERENCES.

1. C.I.E. Proc., 1931, p.19.
2. G. T. Winch and E. H. Palmer, Trans. I.E.S. (London), Oct. 1937.
3. J. T. Randall, Jour. Roy. Soc. Arts 85, 1937.
   J. W. Ryde, Trans, Ill. Eng. Soc. III., Aug. 8th, 1938.
4. H. G. Jenkins, C. D. Brown, G.E.C. Jour. IX., 3, Aug. 1938.

Instruments Incorporating Thermionic Valves, and their Characteristics.

PART II.

By E. G. JAMES, B.Sc., Ph.D., G. W. WARREN, B.Sc., F.Inst.P.
G.E C. Research Laboratories, Wembley, England.

and G. R. POLGREEN, B.Sc., M.I.E.E.
Salford Electrical Instruments, Ltd.

The first part of this paper, which was read before the Meter and Instrument Section of the Institution of Electrical Engineers on January 6th, 1939, was published in the last issue of the G.E.C. Journal. Part II discusses the use of valve instruments for the measurement of D.C. voltages, and methods of measuring current and power. Reference is also made to various other applications such as harmonic analysis, frequency measurement, and the measurement of physical quantities. The article concludes with a brief comparison between valve operated and other types of instrument, and indicates possible future lines of development.

THE MEASUREMENT OF D.C. VOLTAGE.

AS in the case of A.C. measurements, the principal advantage of the valve voltmeter for direct current lies in the extremely small amount of power absorbed from the source. It is, however, only in rather exceptional circumstances, when the combination of very high input-resistance and high sensitivity is required, that D.C. valve voltmeters are used in preference to moving-coil or electrostatic instruments.

In the simplest form of D.C. valve voltmeter the voltage to be measured is superimposed on a fixed negative bias applied to the grid of a triode and the change in anode current measured, the valve having first been calibrated from a known voltage source. Increased sensitivity and a linear scale can be obtained by balancing out part of the anode current and operating the valve over the linear portion of the I_a/E_g characteristic, the limit of sensitivity being determined by the anode-current meter and by variations in valve characteristics and supply voltages.

A more usual method is, however, to apply the unknown voltage to the grid of a triode in opposition to a known voltage from a potentiometer, as shown in fig. 23. With the switch S in Position 1, a fixed negative bias of a few volts is applied to the grid to prevent grid current from flowing, and the anode current is noted (or, for greater sensitivity, the resistance bridge in the anode circuit adjusted to give an arbitrary scale-reading on the galvanometer). The voltage to be measured is applied to the input terminals AB and the potentiometer adjusted until no change occurs on switching from Position 1 to Position 2. The accuracy of the instrument is independent of changes in valve characteristics or supply voltages (provided these changes are not too sudden), and voltages as low as 0·1 mV can be measured with quite a robust galvanometer in the anode circuit provided sufficient care is taken in designing the switch S. If ordinary receiving valves are used, the input resistance of the voltmeter will be at least 10^8 ohms.

For some purposes, *e.g.*, the measurement of glass-electrode potentials in the determination of hydrogen ion concentration, considerably higher input-resistance and greater stability are, however, necessary, and here two methods are available.

The first makes use of an ordinary triode with the grid operated at its "floating" potential, *i.e.*, the potential (usually about 1 volt negative with respect to the cathode) which the grid will acquire when left free. When the valve is in this condition the various components of grid current mentioned in Section, "Valve Characteristics" (*b*), exactly balance one another, as indicated by the point P in fig. 9, and the grid-cathode circuit imposes zero load on an external circuit to which it may be connected. If, therefore, the voltage of the bias battery C shown in fig. 23 is chosen to equal the floating grid potential, the input resistance of the valve voltmeter is infinite. The actual value of the floating grid potential depends, however, on the contact potential-difference between grid and cathode, the residual gas pressure in the valve, inter-electrode leakage, and the values of anode current and anode voltage. Fluctuations in the first three of these parameters are to a large extent avoided by ageing the valve for a long period, but rather elaborate circuits are necessary in order to compensate for anode-current and supply-voltage variations. The theories of such circuits have been discussed fully elsewhere, [18], [19], [20], [21] and [22] and a summary of the various methods, their relative advantages, and their limitations, has been given

by Nottingham.[23] Probably the most satisfactory circuit is that in which two valves are employed which, with their anode resistances, are arranged to form a resistance bridge. Fig. 24 shows the circuit of an instrument of this type which has been described by McFarlane.[24] The grid of the valve

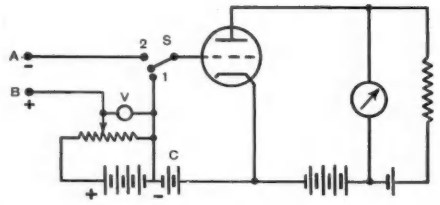


Fig. 23.—Valve voltmeter for measuring D.C. voltage.

to which the input is applied is adjusted to its floating potential, and by means of adjustments to the positions of the contacts P, Q and R a condition can be reached at which quite large variations in the supply voltage and in the valve characteristics do not upset the zero of the instrument. A sensitivity of 0·1 mV is claimed and, provided the grid A.C. resistance ($\delta E_g/\delta I_g$) at the floating potential is greater than 10^9 ohms, a condition satisfied in most valves, slight fluctuations in the actual value of this potential will not seriously upset the input resistance.

The second method, first described by Harrison[25] makes use of a valve of the electrometer type mentioned earlier in this paper (see fig. 10) in which the grid current is extremely low at *any* negative potential greater than about 2 volts (fig. 11). Valves of this type are designed to operate at low anode potentials, and Morton[26] has described a portable instrument using the Type E.T.1 valve with a self-contained potentiometer, standard cell, and robust galvanometer. The potentiometer current, grid bias, filament current, anode voltage, and compensating current are derived from a common source and are standardized in one operation. The input resistance is about 10^{15} ohms, and the instrument is self-adjusting for fluctuations in battery voltage (fig. 25).

Compton and Haring[27] have described a compensated thermionic electrometer in which use is made of the electrometer tetrode Type FP54. Compensation for fluctuations in battery voltages is here effected by balancing the current-changes in the anode and the space-charge grid circuits, and it is claimed that the instrument compares favourably with bridge circuits both as regards stability and sensitivity.

A D.C. voltmeter has recently been described by Smith and Sullivan[28] in which use is made of a type of tuning indicator frequently employed in radio receivers. This consists of a combination of a triode valve and a sector-shaped cathode-ray beam which falls on a fluorescent screen, the angle of the beam and therefore the fluorescing area of the screen being controlled by an auxiliary electrode connected to the anode of the triode. Fig. 26 shows the relation between the angle of the non-fluorescing sector of the screen and the voltage applied to the grid of the triode component for a valve of this type (Y63) under normal operating conditions. Although high accuracy cannot be claimed for this type of instrument, it possesses the advantages of robustness and portability (there are no delicate moving parts), and, furthermore, the electron beam—having negligible inertia—follows instantaneously rapid changes in the voltage applied to the triode.

In the measurement of small D.C. voltages, whether by valves operating at the floating grid potential or by electrometer valves, very complete screening is necessary in order to avoid stray alternating currents being picked up in the input circuit and rectified by the valve, and also to prevent charges from accumulating on the bulb of the valve which would disturb the characteristics. In many cases it is recommended that the valve should be operated in the dark to prevent the emission of photo-electrons from the grid.

THE MEASUREMENT OF CURRENT.

In normal instrument practice, current is measured either by its magnetic or by its heating effect, and voltage is determined by measuring the current through a known resistance. In the case of instruments employing valves the converse pro-

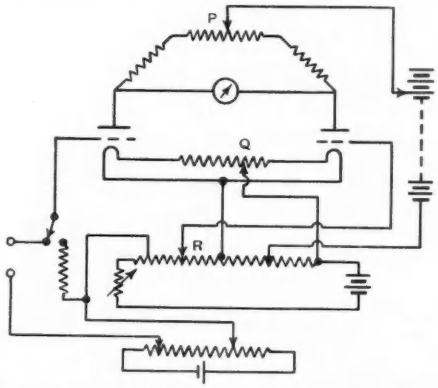


Fig. 24.—Valve voltmeter for D.C. voltages described by McFarlane.

cedure is adopted. Voltage is measured by its controlling action on the electron current in the valve, while current may be determined by measuring the voltage produced across a known resistance. This method is particularly suitable for the measurement of extremely small currents, either alternating or direct, which can be passed through a fairly high resistance, and any of the valve voltmeters men-

tioned above may be used in this way. Du Bridge[29] has described several circuits using the electrometer tetrode Type FP54 and has found it possible to measure direct current of the order of 10^{-16} amp. by this means. Soller[30] and Moles[31] have also described methods of obtaining comparable sensitivity, while

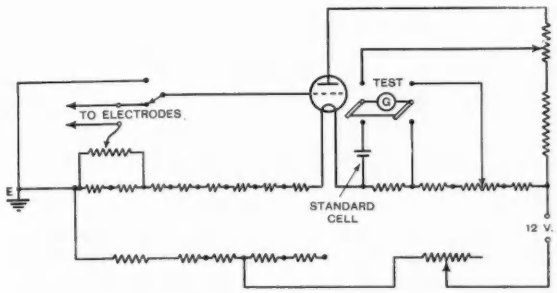


Fig. 25.—Valve electrometer described by Morton.

Teegan and Hayes[32] have used the electrometer triode Type E.T.1 for the measurement of small ionization currents of similar magnitude. Winch and Harper[33] have employed the electrometer triode to measure small photo-electric currents and have designed an instrument for photometric measurements in which the electrometer and photocell together with a grid resistance of 50 megohms are sealed into an evacuated glass bulb to prevent leakage currents due to moisture on the outside surface of the valve (fig. 27).

For greater sensitivity, additional stages of valve amplification may be used, but with such amplifiers, particularly in D.C. measurements, variations in valve

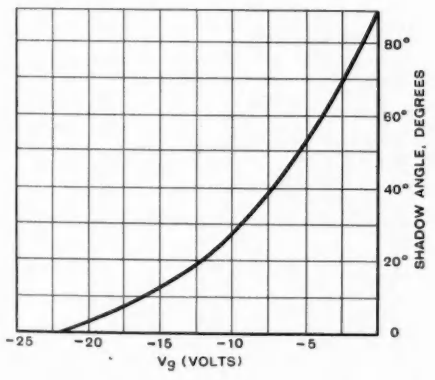


Fig. 26.—Variation of shadow angle with grid voltage for Y.63 valve.

characteristics and voltages are troublesome. If, however, negative feedback is applied to the amplifier, the effect of variation of electrode voltages on the gain can be reduced to negligible proportions.

It has been shown* that the gain m_1 of an amplifier in which a fraction β of the output is fed back in series with the input is given by

$$m_1 = \frac{m}{1 + m\beta}$$

If $\beta = 1$, *i.e.*, if all the output is connected in series with the input,

$$m_1 = \frac{m}{1 + m} = 1 - \frac{1}{1 + m}$$

If the gain, m, of the amplifier without feedback is large, $m_1 \simeq 1$, and the output voltage is equal to the input voltage, being independent of variations in the supply voltages to the amplifier valves.

If R_1 is the input resistance to the amplifier, R_2 the output resistance, I_1 the input current, and I_2 the output current,

Then $$R_1 I_1 = R_2 I_2$$

and $$I_1 = \frac{R_2}{R_1} I_2$$

If a current meter is connected in series with R_2 or a voltmeter connected across R_2, the instrument becomes a voltmeter whose resistance is determined solely by the resistance R_1. By using a wide range of input resistances the instrument becomes an ammeter with a corresponding wide range. Since the power supplied to the output meter is supplied by the H.T. voltage through the output valve, a rugged and accurate meter of low sensitivity may be

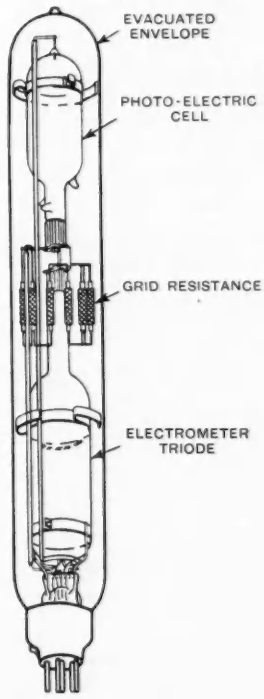


Fig. 27.—Electrometer-photocell unit.

* See Section "Valve Characteristics," Part 1.

used, while great sensitivity may be obtained by the use of high input resistances.

A. W. Vance[34] describes such an instrument in which a 0·1 volt voltmeter is used as the output meter. Hence with an input resistance of 10^7 ohms, full-scale deflection is obtained with a current of 10^{-8} amp., while with 100 ohms input resistance a current of 1 milliamp. would give full-scale deflection. The amplifier output can be so designed that the maximum output obtainable is insufficient to damage the output voltmeter, so that the instrument can stand very large overloads.

Another method of current measurement depends for its action on the use of a diode valve, operated under saturation conditions. When the filament of a thermionic diode is heated to an absolute temperature τ, the saturation current is given by

$$I_s = A\tau^2\varepsilon^{-b/\tau}$$

where A and b are constants.

The filament can be heated by either direct current or alternating current, while saturation current can be measured with a D.C. instrument. The valve therefore enables one to measure an alternating current in terms of a direct current.

One instrument employing the above principle is described by Barlow.[35] The filament of a diode is heated in the first place by a direct current to a temperature somewhat below the normal working temperature, and the H.T. voltage applied is sufficiently positive to saturate the anode current. The valve is arranged as one arm of a resistance-bridge network, a moving-coil galvanometer indicating when the bridge is balanced (fig. 28). The alternating current is superposed on the direct current through the filament of the valve, thereby increasing the temperature and anode current and upsetting the balance of the bridge. The reading of the galvanometer is calibrated to read directly the value of the alternating current. The balance of the bridge depends critically on the direct current through the filament, so that any variation in the filament-battery voltage will cause a troublesome drift in the zero of the instrument. To overcome this difficulty one arm of the bridge can be replaced by another similar diode, the two filaments being run in series; the stability is then greatly improved and the sensitivity increased.

The instrument has the advantages that R.M.S. values are measured whatever the wave-form, the overload capacity is large, and different ranges can be provided by varying the series or shunt resistance of the galvanometer; but it has the disadvantage that it cannot be calibrated with direct current as in the case of vacuo-thermo junctions.

The frequency range is determined by the design of the circuit for applying the alternating current to the instrument. Barlow shows that the instrument can be designed to have an accuracy better than 1% for a frequency range between 25 and 5×10^6 cycles per sec.

Another instrument employing the same principle is described by Martyn.[36] Alternating current from a local oscillator supplies the main heating current of the filament, and the alternating current to be measured is superimposed on the current from

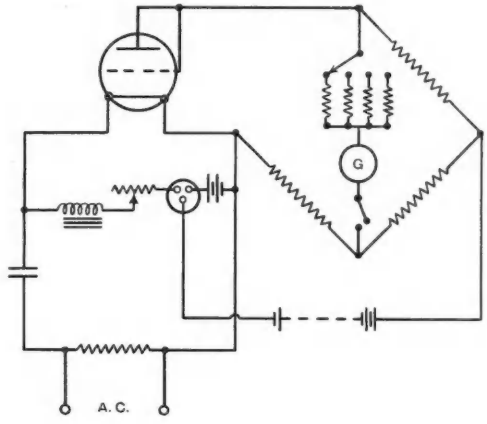


Fig. 28.—Circuit of valve ammeter described by Barlow.

the local oscillator. When the frequency of the oscillator is varied the anode current of the diode is constant at first; then the needle of the instrument begins to oscillate, the amplitude increasing until the two frequencies are the same. Synchronization then takes place, the two currents "locking" in phase or in antiphase, and the anode current reaches a pronounced maximum or minimum value. The value of the unknown alternating current is determined from the difference between the values of the anode current in the synchronized condition and in the condition when the frequencies differ so widely as to produce a constant reading. Although the method seems more complicated than that of Barlow, the sensitivity is such that an alternating current of 1 microamp. produces a change in the anode current (D.C.) of 0·5 microamp.

VALVE WATTMETERS.

The measurement of small amounts of power at radio frequency presents a difficult problem. Ordinary low-frequency wattmeters cannot be used because of their inductive and capacitive effects. The use of thermionic triodes, however, enables very small powers to be measured with a fair degree of accuracy.[37] and [38]

The circuit of such a wattmeter is shown in fig. 29. R, R are equal non-inductive resistors and R_s a high-resistance potentiometer. The galvanometer G is arranged to measure the difference in the anode currents of the two triodes V_1 and V_2.

If v is the voltage across R_s, and i the current flowing through the resistors R, R (i is the load current), then the voltages applied to the grids of V_1 and V_2 respectively are

$$\left(\frac{r}{R_s}v+Ri\right) \quad \text{and} \quad \left(\frac{r}{R_s}v-Ri\right)$$

The anode-current/grid-voltage characteristic of a suitably designed triode is a parabola* over a considerable voltage range. That is,

$$I_a=a_1+a_2V_g+a_3V_g^2$$

The anode currents of the two valves may therefore be written as

$$I_1=a_1+a_2\left(\frac{r}{R_s}v+Ri\right)+a_3\left(\frac{r}{R_s}v+Ri\right)^2$$

$$I_2=a_1+a_2\left(\frac{r}{R_s}v-Ri\right)+a_3\left(\frac{r}{R_s}v-Ri\right)^2$$

if the valves are identical. The difference, which is read on the galvonometer, is:

$$I_1-I_2=2a_2Ri+4a_3\frac{Rr}{R_s}vi$$

If $V=E\cos(\theta+\phi)$ and $i=I\cos\theta$

then $I_1-I_2=2a_2RI\cos\theta+4a_3\frac{Rr}{R_s}EI\cos\theta\cos(\theta+\phi)$

The direct component of this expression (which is the only component read by the galvanometer) is

$$4a_3\frac{Rr}{R_s}EI\cos\phi$$

That is, the galvanometer deflection is proportional to the power ($EI\cos\phi$).

A small error is introduced by the power dissipated in the resistors R, but this is usually negligible, so that the instrument is direct-reading. A correction can, however, be made when the power to be measured is very small. By a substitution of the resistors, a range of powers from 1 milliwatt to an indefinitely large value can be measured with a fair degree of accuracy.[38]

Another type of valve wattmeter is described by J. R. Pierce[39] in which a multi-electrode valve of the hexode (or heptode) type is used. The disposition of the electrode system is shown in fig. 30. In such a valve, G_2 and G_4 are at a fixed positive potential with respect to the cathode, while G_1 and G_3 are biased negatively. The current passing through G_1 will then be dependent only on the potential of G_1 and G_2, being independent of the potential of G_3, while the proportion of this current reaching the anode will depend only on the potential of G_3 and G_4. If the anode-current/grid-voltage characteristics of G_1 and G_3 are both linear, then the anode current will be represented by

$$I_a=A_1V_{g_1}+A_2V_{g_1}V_{g_3}+A_3V_{g_3}+A_4$$

If alternating voltages $E_1\cos\theta$ and $E_2\cos(\theta+\phi)$ are applied to the grids G_1 and G_3, the only D.C. component of I_a will be given by the second term in the above expression and will be equal to $A_2E_1E_2\cos\phi$, *i.e.*, the change in reading of a D.C. instrument in the anode circuit is proportional to the power, if E_1 is made proportional to the voltage and E_2 to the current in the load. Existing multi-electrode valves have such a small range of linearity that an error is introduced due to anode-bend rectification, but if two valves in push-pull are used the error is considerably reduced: Pierce[39] describes such an arrangement in which powers ranging from 10 milliwatts to 200 watts can be measured.

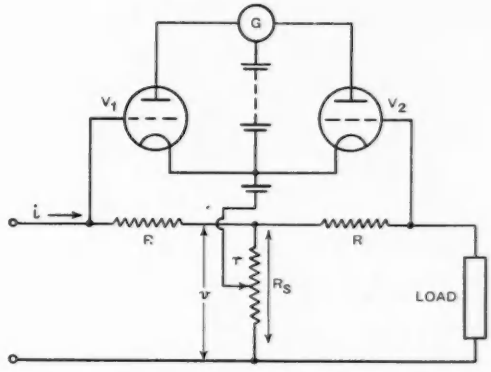


Fig. 29.—Valve wattmeter.

HARMONIC ANALYSERS.

Most harmonic analysers in which a valve is the essential part of the instrument depend for their operation on the parabolic anode-current/grid-voltage characteristic of the valve, namely

$$I_a=a_1+a_2V_g+a_3V_g^2$$

If a sinusoidal voltage $E_0\cos\omega_0t$ and a voltage E of complex wave-form are applied in series to the grid of the valve, the anode current will be given by

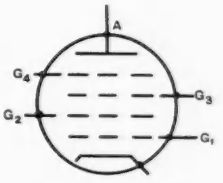


Fig. 30.—Disposition of the electrode system in a hexode valve.

$$I_a=a_1+a_2(E_0\cos\omega_0t+E)+a_3(E_0\cos\omega_0t+E)^2$$

If $E=E_1\cos\omega_1t+E_2\cos\omega_2t+E_3\cos\omega_3t+\ldots$

then

$$I_a=a_1+a_2(E_0\cos\omega_0t+E_1\cos\omega_1t+E_2\cos\omega_2t+\ldots$$
$$+a_3(E_0\cos\omega_0t+E_1\cos\omega_1t+E_2\cos\omega_2t+..)^2$$

* See Section "Valve Characteristics," Part 1

This expression, when expanded, contains terms of frequency given by :—

$$\omega_0,\ \omega_1,\ \omega_2,$$
$$(\omega_0+\omega_1),\ (\omega_1+\omega_2)$$
$$(\omega_0-\omega_1),\ (\omega_1-\omega_2),\ \ldots \text{ etc.}$$

If, however, ω_0 is made almost equal to ω_1, the only very low-frequency component of I_a is $a_3E_0E_1\cos(\omega_0-\omega_1)t$. If now ω_0 is changed to be almost equal to ω_2, the only low-frequency component will be $a_3E_0E_2\cos(\omega_0-\omega_2)t$, and similarly for the ω_3, ω_4, etc., harmonics. That is, if the frequency of the local sinusoidal oscillation is adjusted to be very nearly equal to the frequency of the harmonic to be measured, the needle of the anode-current measuring instrument will oscillate slowly in response to the difference frequency.[40] The amplitude of swing of the needle will be

$$I_1=2a_3E_0E_1 \text{ for the fundamental,}$$
$$I_2=2a_3E_0E_2 \text{ for the 2nd harmonic,}$$
$$I_3=2a_3E_0E_3 \text{ for the 3rd harmonic,}$$
etc.

The coefficient 2 takes into account the maximum positive and negative values of $\cos(\omega_0-\omega_1)t$, etc.

The peak amplitude of any harmonic is therefore given by

$$E_n=\frac{I_n}{2a_3E_0}$$

If E_0 is kept constant, the ratio of any harmonic to the fundamental is the ratio of I_n to I_1, while the absolute values can be determined if a_3 and E_0 are known.

If the output of the local oscillator contains harmonics, beat notes may be obtained between them and the harmonic which it is desired to measure. But if the local oscillator does not contain more than a few per cent of harmonics, the error can be shown to be negligible.

If the characteristic is not parabolic, a term $a_4V_g^3$ will appear in the equation, and it can be shown that the current amplitude due to the 2nd harmonic will then be

$$I_2=2a_3E_0E_2+\frac{3a_4}{2}E_0E_1^2$$

Thus a term $\frac{3a_4}{2}E_0E_1^2$ is introduced, but it can be made negligible by making E_1 small. This, however, reduces the sensitivity of the instrument, which is undesirable. The difficulty can be overcome by using two valves in push-pull;[40] the anode-current changes due to the terms a_2V_g, $a_4V_g^3$, etc., then cancel out, and the error due to $a_4V_g^3$ is eliminated.

If, however, a fourth-order term is present in the characteristic, a spurious third harmonic is produced in each valve, and these add together in the push-pull arrangement. The fourth-order term, however, is found to be very small in practice and may be neglected.

The order of accuracy that is obtainable with the instrument is better than 1% for a harmonic of 10% of the fundamental, and about 3% for a 1% harmonic.

If, instead of adjusting the frequency of the local oscillator to be approximately equal to that of the harmonic to be measured, one adjusts the frequency so that $(\omega_0-\omega_1)$, etc., are always equal to ω', then the component of frequency $\omega'/(2\pi)$ can be amplified by a selective amplifier tuned to $\omega'/(2\pi)$, and the output read on a meter. This system has the advantages that the sensitivity is increased so that the input to the analyser can be kept small, thereby decreasing the error due to the unbalanced cube term. The output reading is then proportional to the amplitude of the harmonic, and it does not necessitate taking the difference of two readings as in the first method.

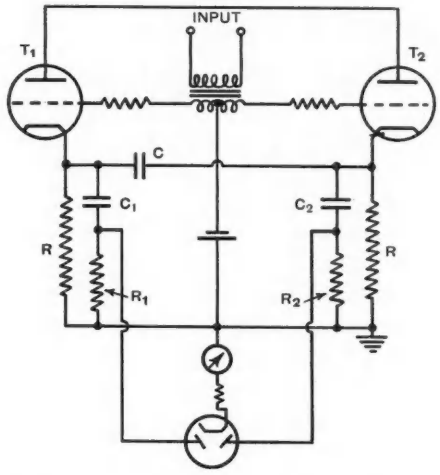


Fig. 31.—Direct reading frequency meter.

MEASUREMENT OF FREQUENCY.

The common methods of measuring frequency are bridge methods and the use of calibrated tuned circuits, resonance being indicated by voltage or current. Neither of the methods is direct-reading, and therefore rapid changes of frequency cannot be measured.

A direct-reading audio-frequency meter is described by F. V. Hunt[41] in which rapid variations in frequency can be measured, and which is suitable for recording frequency as a function of time. The instrument employs two gas-filled triode valves in conjunction with a double-diode valve. The circuit is shown in fig. 31.

The signal whose frequency it is desired to measure is applied to the grids of two gas-filled triode valves T_1 and T_2 in push-pull, so that when the grid of T_1 goes more positive the grid of T_2 goes more negative. If at any instant T_1 is carrying its normal discharge current, while T_2 is non-conducting, then the condensers C and C_1 become charged to a potential V_R, equal to the drop across the load resistance R in the cathode of T_1, while C_2 is uncharged. If, now, the input signal varies so that the grid of T_2 becomes more positive, arc discharge will be initiated in T_2, and the potential of the cathode of T_2 will be raised abruptly to a value V_R. As the voltage across the condenser C cannot alter instantaneously, the cathode of T_1 will momentarily be made more positive with respect to its anode, and since its grid is at this instant negative, the arc in T_1 will be extinguished, provided the de-ionization time of the valve is not greater than the time required for C to discharge through R. Similarly the voltage of one anode of the double-diode valve will be raised momentarily and a current pulse will be delivered to the indicating instrument. When the input signal next varies in such a way that the grid of T_1 becomes more positive a similar sequence of events takes place.

Since the average current in the indicating instrument is proportional to the number of pulses delivered per second, it follows that the current is proportional to the frequency. The linear relation holds up to about 7,000 cycles per sec., above which the linearity is affected in consequence of the capacitance across the diode load and the time-constants of the *RC* circuits. The upper limit is determined by the de-ionization time of the relays.

Typical examples of the application of such an instrument are the recording of rapid frequency variations occurring in speech and singing, the recording of the decay of artificial radio-activity, and frequency monitoring or control.

USE OF VALVE OSCILLATORS FOR MEASURING PHYSICAL QUANTITIES.

The change in frequency of a valve oscillator when the tuning capacitance is altered has been used for measuring changes in quantities such as length.[42] The change in length in the specimen is made to alter the capacitance of a parallel-plate condenser, and as the change in frequency can be determined very accurately very small changes in length can be measured.

As well as changing the frequency, a change in the tuning capacitance gives rise to a change in the impedance of the circuit and therefore in the amplitude of the oscillation. As the anode-current/anode-voltage and anode-current/grid-voltage characteristics of a triode are curved, anode-bend rectification takes place. Hence a change in the amplitude of the oscillation will give rise to a change in anode current, the anode current increasing when the amplitude increases. On the other hand, if the oscillator is self-biased, *i.e.*, if a grid leak and condenser are used, the current through the grid leak will be approximately proportional to the amplitude of the oscillation. The grid current can therefore be taken as a measure of the amplitude. It will also give rise to an increased negative bias, so that the anode current in this case will decrease.

Several circuits have been described using the above methods for the determination of changes in physical quantities.[43], [44], [45], and [46] It has been shown that, by a suitable design of the oscillator circuit and the use of a sensitive current instrument, changes in length of about 10^{-6} to 10^{-7} cm. can be measured.

USE OF VALVES FOR RESISTANCE MEASUREMENT.

It has been shown that the grid-current/grid-voltage characteristic of a triode valve is approximately exponential for small currents. That is,

$$I_g = G\varepsilon^{KV_g}$$

where V_g is the negative grid voltage and G and K are constants if the anode voltage is fixed.

If a resistance R is connected between grid and cathode, then

$$\frac{V_g}{R} = -I_g$$

$$\therefore -\frac{V_g}{R} = G\varepsilon^{KV_g}$$

or $$\log R = \log V_g + KV_g + \text{Constant}$$

The anode current of the valve is determined by the grid voltage; therefore a definite relation exists between the anode current and the resistance R in the grid circuit.

The method has been used for the measurement of high resistances.[47] Fig. 32 shows the relation between the anode current I_a and log R, using a selected H63 valve. The slope of the curve changes very little for the range of resistance between 10,000 ohms and 100 megohms, and the order of accuracy to which the resistance can be measured is about 5%. For values of resistance above 100 megohms the slope of the curve decreases, but the instrument can still be used as an indicator to show that a resistance is above a certain value.

If a high positive voltage is included in series with the resistance, very much higher resistances can be measured, and the voltage can be adjusted to correct for any change that might occur in the contact potential between grid and cathode.

COMPARISON OF VALVE-OPERATED INSTRUMENTS WITH OTHER TYPES.

The valve voltmeter, together with its application

as a means of measuring current, is the most important of the various types of instrument which have been described, and it is interesting to compare it with alternative forms of instruments. The first instrument incorporating the thermionic valve—the valve voltmeter—was introduced mainly for high-frequency measurement where a high impedance was essential. Because of its unstable performance, poor scale shape, and difficulty of operation, together with the need for frequent recalibration, the early valve voltmeter was mainly confined to the laboratory for use by skilled observers. For several years, however, other types of instrument were unsuited to general high-frequency measurements with the exception of the thermocouple ammeter, which has maintained its usefulness as a laboratory instrument as a means of obtaining accurate comparison of alternating current with direct current. However, for voltmeters and ammeters of medium accuracy at radio frequencies, the chief disadvantages of instruments utilizing thermojunctions, namely small overload capacity, sluggishness of reading, and, unsuitable scale shape for most purposes, have been overcome for many applications by recent improvements in metal rectifier instruments. The latter are now made to read currents of several amperes up to the higher radio frequencies, and full-scale voltages from 1 volt upwards at frequencies up to 1 or 2 Mc./sec. The impedance of such instruments, while not of the same order as that of the valve voltmeter, is adequate for many purposes where small and inexpensive instruments are required.

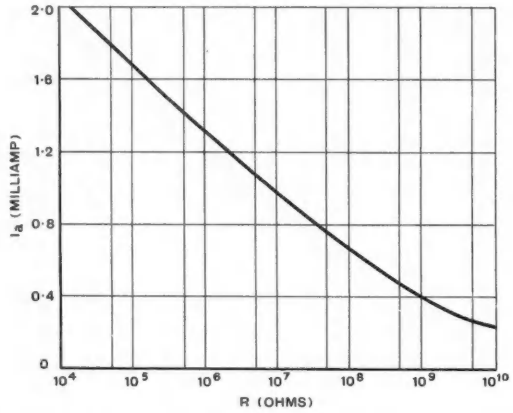


Fig. 32.—Relation between anode current and grid resistance for the triode H.63.

A disadvantage often quoted in connection with valve voltmeters is the wave-form error to which they are liable. While it is true that in this respect these instruments compare unfavourably with thermal instruments, valve voltmeters are mostly used under conditions where the wave-form can be controlled. Thus, in those cases where they are used in conjunction with local oscillators, the distortion of the wave from sinusoidal form can be reduced to such small proportions that the wave-form error in the valve voltmeter is negligible. This applies especially to the series of instruments known as Q-meters, loss-factor meters, C-meters, etc., which consist of self-contained oscillators and valve voltmeters, the latter being calibrated directly in the quantity it is desired to measure. This application of thermionic valves in the field of electrical measurements is becoming increasingly important, not only for electrical measurements of all types, but also for the testing of the purity and properties of such materials as oils, insulating materials, and chemical substances by the direct measurement of their dielectric constant and power factor.

From this brief analysis it will be seen that the chief field of application of the valve-operated instrument is multi-range test equipment of medium size, associated in many instances with amplifiers and local oscillators in order that adequate range and flexibility of testing may be obtained. In the past, the valve-type instrument has had exclusive applications in the medium-frequency and high-frequency field, but, where low cost and very small size are essential, latest developments indicate that thermal and metal-rectifier types of instrument will meet many of the practical requirements for frequencies up to and including ranges commonly used for radio and carrier telephony transmission.

FUTURE DEVELOPMENTS.

It is interesting to note that although the first reference to the use of valves for measurement purposes was made as early as 1916,[48] Dr. Drysdale made no mention of the thermionic valve as a factor in the future of electrical instruments in a paper entitled "Future Progress in Electrical Measuring Instruments," read before The Institution of Electrical Engineers 5 years ago. At that period, although the use of valve-operated instruments was considerable in the fields of radio and telephony, the thermionic

Fig. 33.—Battery operated diode voltmeter.

valve was not considered to be important for general electrical measurements.

Since that time special valves have been developed for instrument applications, some of which have been described in this paper. The practical construction of valve-operated instruments has also been greatly improved; whereas formerly the valve voltmeter consisted of several components and controls, the modern instrument of this type is self-contained and is generally operated from A.C. mains. In overall size and portability it does not greatly vary from other multi-range test instruments, and the fact that an outside source of supply is required does not hamper its efficiency now that satisfactory means of controlling mains-voltage fluctuations are in widespread use.

Simple and inexpensive valve-voltmeters can be made to operate from pocket-lamp batteries, thus making a useful self-contained instrument with the general advantages of very high impedance and wide frequency range. An example of such an instrument is shown in fig. 33.

One of the most important advances in the application of the valve to electrical measurements is the development of the negative feed-back amplifier. This opens up an extensive field of development in the construction of multi-range instruments with sensitive A.C. and D.C. ranges. In the past, instrument makers have striven towards the manufacture of more sensitive instruments by the use of new material, and improved mechanical construction of the indicating mechanism. While remarkable progress has been made in this direction, there is always the limiting factor of robustness; for instance, in the case of direct-current instruments, the use of portable galvanometers has enabled very small currents to be measured accurately for industrial as well as for laboratory testing. Such instruments are, however, always liable to damage by mechanical shock and electrical overload, and in the more sensitive types are affected by vibration, and appreciable time is required to take a reading. The stabilized valve amplifier has considerable possibilities both for sensitive D.C. measurements and for A.C. measurements, and has the advantages of robustness, portability and flexibility of scale shape. Moreover, it is possible to make such an instrument with an almost unlimited overload capacity, a feature which is seldom available in other types of instrument, and which is specially valuable in sensitive multi-range instruments. In using such an instrument, the current or voltage to be measured can be connected to the terminals with the range switch in any position, and the switch position can be altered until a suitable reading is obtained. There is no fear of damaging the instrument by excess voltage or current up to the limit of the current-carrying capacity of the input resistances.

Such an amplifier-type valve-operated instrument has other important applications where the available power is very small. In particular may be mentioned the measurement of very high insulation values, and numerous applications in the extensive fields of sound, temperature, and light measurement.

In conclusion, the authors desire to tender their acknowledgment to the Marconiphone Co. and The General Electric Co., Ltd., whose research work on electrical instruments and valves has inspired this review.

BIBLIOGRAPHY.

18. C. E. Wynn-Williams: "A Valve Amplifier for Ionization Currents." Proc. Camb. Phil. Soc. 1927, Vol. 23, p. 811.
19. C. E. Wynn-Williams: "The Application of a Valve Amplifier to the Measurement of X-ray and Photo-electric Effects." Phil. Mag., 1928, Vol. 6 p. 324.
20. J. Bretano: "The Application of a Valve Voltmeter to the Measurement of X-ray and Photo-electric Effect." Phil. Mag., 1929. Vol. 7, p. 685.
21. J. M. Elgin: "A Direct Current Amplifier for Measuring Small Currents. Journal Opt. Soc. America, 1929, Vol. 18, p. 393.
22. J. Razek and P. J. Mulder: "A Bridge Grid Resistor Amplifier." Journal Opt. Soc. America, 1929, Vol. 19, p. 390.
23. W. B. Nottingham: "Measurement of Small D.C. Potentials." Journal Franklin Inst., 1930, Vol. 209, p. 287.
24. A. S. McFarlane: "Some Aspects of the Valve Bridge with a Description of a New Compensated Valve Voltmeter." Phil. Mag., 1932, Vol. 14, p. 1.
25. G. B. Harrison: "The Application of a New Type of Triode Valve to the Determination of Hydrogen-ion Concentration with Glass Electrodes." Journ. Chem. Soc., 1930, p. 1,528.
26. C. Morton: "A Portable Thermionic Electrometer for the Determination of Glass-electrode Potentials." Journal Sci. Instr., 1932, Vol. 9, p. 289.
27. K. G. Compton and H. E. Haring: "A Compensated Thermionic Electrometer." Trans. Electrochemical Soc., 1932, Vol. 62, p. 345.
28. G. F. Smith and V. R. Sullivan: "The Electron Beam Sectrometer." Journal Soc. Chem. Ind., 1937, Vol. 56, p. 104 T.
29. L. A. Du Bridge: "The Amplification of Small Direct Currents,' Phys. Rev., 1931, Vol. 37, p. 392.
30. W. Soller: "One-Tube Balanced Circuit for D.C. Vacuum Tube Amplifiers of Very Small Currents." Rev. Sci. Instr., 1932, Vol. 3, p. 416.
31. F. J. Moles: "A Supersensitive Amplifier for Measuring Small Currents." G. E. Review, 1933, Vol. 36, p. 156.
32. J. A. C. Teegan and A. M. Hayes: "The Application of the Electrometer Triode to the Measurement of Ionization Current." Journal Sci. Instr., 1933, Vol. 10, p. 130.
33. G. T. Winch and C. T. Harper: "The Development of Commercial Photoelectric Photometers." G.E.C. Journal, 1932, Vol. 3, p. 150.
34. A. W. Vance: "An Improved Vacuum Tube Microammeter." Rev. Sci. Instr., 1936, Vol. 7, p. 489.
35. H. E. M. Barlow: "A Valve Ammeter for the Measurement of Small Alternating Current of Radio Frequency." Journal I.E.E., 1935, Vol. 77, p. 612.
36. D. F. Martyn: "On a New Method of Measurement of Minute Alternating Currents." Proc. Roy. Soc. Edinburgh, 1930, Vol. 50, p. 166.
37. H. M. Turner and F. T. McNamara: "An Electron Tube Wattmeter and Voltmeter and a Phase Shifting Bridge." Proc. I.R.E., 1930, Vol. 18, p. 1,743.
38. E. Mallett: "A Valve Wattmeter." Journal I.E.E., 1933, Vol. 73, p. 295.
39. J. R. Pierce: "A Proposed Wattmeter using Multi-electrode Valves." Proc. I.R.E., 1936, Vol. 24, p. 577.
40. W. Greenwood: "A Valve Voltmeter Method of Harmonic Analysis." Exp. Wireless and Wireless Eng., 1932, Vol. 9, p. 310.
41. F. V. Hunt: "A Direct Reading Frequency Meter for High Speed Recording." Rev. Sci. Instr., 1935, Vol. 6, p. 43.
42. R. Whiddington: "The Ultra-micrometer: An Application of the Thermionic Valve to the Measurement of Very Small Distances." Phil. Mag., 1920, Vol. 40, p. 634.
43. H. A. Thomas: "Electrical Apparatus for Measuring Small Motions." Engineer, 1923, Vol, 135, p. 138.
44. J. J. Dowling: "The Recording Ultra-micrometer; Its Principles and Application." Phil. Mag., 1923, Vol. 46, p. 81.
45. W. D. Oliphant: "On the use of the Pentode Valve for Pressure Recording." Journal Sci. Instr., 1932, Vol. 9, p. 386.
46. F. De La C. Chard: "An Application of the Thermionic Valve to the Measurement of Physical Quantities." Journal Sci. Instr., 1935, Vol. 12, p. 191.
47. A Preisman: "High Resistance Measurement with Vacuum Tubes." Electronics, 1935, Vol. 8, p. 214.
48. C. H. Sharpe and E. D. Doyle: "Crest Voltmeters," Trans. A.I.E.E., 1916, Vol. 35, p. 99.
49. J. Greig and H. N. Wroe: "A Low-Reading Mean Voltmeter." Exp. Wireless and Wireless Eng., 1938, Vol. 15, p. 658.

Plastics and the Electrical Industry.

PART I.

By A. E. PHIPPS,
G.E.C. Moulded Insulation Works, Witton.

The author outlines the development of modern plastic materials, the manufacture and moulding of the principal types with details of their characteristics and properties.

In Part I the thermo-setting materials, both phenolic and urea, are dealt with, and a description is given of modern manufacturing methods together with details of those qualities which have made the materials of particular value to the electrical industry.

In Part II the thermo-plastic materials will be considered as well as questions of the design of mouldings.

THE rapid progress made by the plastics industry during the last twenty-five years is due mainly to the new moulding materials developed as a result of chemical research.

Broadly, a plastic material may be described as one that can be formed into any desired shape under the action of mechanical pressure, with or without the application of heat, and that will retain its shape when the forming pressure is removed. As explained later, the development of the plastics industry has tended to give the word a very specialized meaning.

Mouldings have long been made in the older materials, such as porcelain, hard rubber and resin-bitumen compounds, which, in the early days of the electrical industry, were used for the mouldings required for insulation purposes. All electrical engineers are familiar with the chief limitations of these materials, namely, the brittleness and dimensional inaccuracies of porcelain and the low heat resistance of hard rubber and resin-bitumen compounds.

In the early years of the century, therefore, chemists began to turn their attention to the resin-like masses which can be produced by the interaction of certain chemicals, with a view to their use in place of the natural resins and resin-gums, of which shellac had the most desirable characteristics. Even now this material is difficult to match as regards hardness and toughness.

The supply of the best classes of resins is limited and in consequence they are subject to price fluctuations and adulteration. It was anticipated that, given adequate supplies of raw material, a synthetic substance could be produced to overcome these grave disadvantages. Thus the discovery of a class of fusible resins, which when heated above a certain critical temperature formed infusible and insoluble resins, assumed major importance, and some of these products generally known as thermo-setting resins now form the basis of the resin-filler moulding powders.

The most promising of these resinous masses produced in the laboratory was that formed by the interaction of phenol and formaldehyde, and although the earlier products met with indifferent success, the work of Baekeland resulted in materials which had all the moulding advantages of shellac and, in addition, comparatively great heat resisting qualities. These synthetic products promoted the rapid growth of the moulding industry. During the last fifteen years they have been quickly followed by many other synthetic materials, with the result that an important plastics industry has been built up which not only supplies large quantities of mouldings to the electrical industry, but is rapidly expanding its markets in other directions by reason of the fact that its products in many ways are superior to similar articles made in the older materials, such as porcelain, glass, wood, etc.

Of the many plastic materials available, the plastics industry deals with two main classes only, both organic :—

(1) Plastics made from heat-hardening synthetic resins, where the application of heat, generally under pressure, produces hard, infusible, insoluble products. Typical resins are the phenol-formaldehyde and urea-formaldehyde types.

(2) Plastics made from non-hardening binders. This group includes synthetic and non-synthetic types. Bitumens, both natural and pyrogenous, and natural resins are examples of the non-synthetic types, while the synthetic group includes materials such as polystyrene resins, vinyl resins, methacrylic acid resins and cellulose acetate. The last named may, perhaps, more truly be termed a modified product than a synthetic one.

However, in making a general survey of materials which, by virtue of their plasticity, are capable of being moulded into articles required for purposes of electrical insulation, mention must be made of other substances and, in particular, of porcelain, cement-asbestos and hard rubber, all of which are still used in large quantities on account of certain

properties which they possess and which are not yet equalled in the newer materials.

It may be noted that laminated material made by compressing sheets of paper, or fabric, coated or impregnated with synthetic varnish, cannot strictly be included under the head of moulded insulation, as the articles which can be manufactured from them are limited to sheet, rod, tubes and other very simple shapes.

MOULDING MATERIALS.

The materials available for moulding can be grouped broadly on a process basis.

(a) Hot Moulded Thermo-setting Compounds.

Hot moulded thermo-setting compounds are made by mixing thermo-setting synthetic resins, or binders, with organic and inorganic binders, and moulding in heated moulds under pressure so that the product when extracted from the mould is in finished form and will not soften again on exposure to heat. Phenol-formaldehyde and urea-formaldehyde compounds are representative of this class, of which Bakelite in the first case, and Beetle in the second, are typical.

The telephone case shown in fig. 1 is a typical illustration of the use of phenol-formaldehyde material, while the cream colour ceiling fitting is a good example of the colour obtainable with urea-formaldehyde material.

(b) Hot Moulded Thermo-plastic Compounds.

Hot moulded thermo-plastic compounds were originally composed entirely of materials made by mixing resins, bitumens or pitches with suitable fillers and fibres. In recent years new synthetic materials have been produced, such as polystyrene, methyl methacylate and cellulose acetate, which fall within this group. In all cases, the material is heated before being charged into the moulds proper, and when pressed, the article is allowed to cool in the mould sufficiently to avoid distortion on removal. This class has relatively low heat resistance.

The meter terminal block shown in fig. 1 is an instance of the type of article for which material of the bituminous composition class is particularly suitable, while the telephone cradle is a typical example of the use of cellulose acetate material where the conditions of service make its toughness of special value.

(c) Cold Moulded Compounds.

Cold moulded compounds are frequently termed fireproof, and are made by mixing solutions of resinous or bituminous binders in suitable solvents with inorganic fillers and fibres. The product is moulded in cold moulds and the article removed immediately, as cooling is unnecessary. A baking process is required to harden off the articles. At one time this class of compound was of major importance but except for special applications it has now been largely replaced by suitable types of Class A.

(d) Ceramic Materials.

Ceramic materials, of which porcelain is the best known, are made from mixtures of china clay, silica, felspar and fluxes with water. The processes are entirely different from those used in the other classes, and after moulding and careful drying the products are fired at a high temperature and may be glazed. The resultant articles have very good electrical properties and are non-hygroscopic, but cannot be made to great dimensional accuracy, and suffer from brittleness.

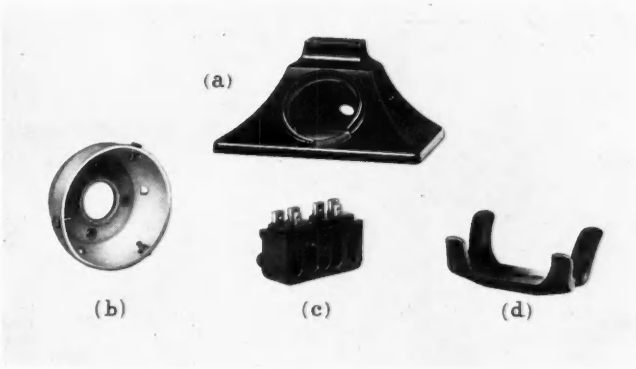


Fig. 1.—Various moulded products illustrating typical uses of the following plastic materials :
(a) Phenol-formaldehyde. (c) Bitumen asbestos.
(b) Urea-formaldehyde. (d) Cellulose acetate.

(e) Hard Rubber Compounds.

Hard rubber compounds are made by mixing rubber with a relatively high proportion of suphur, together with suitable fillers, according to the class of compound required. The resultant compound is hot moulded and vulcanised. At one time, this class was of much greater importance than it is to-day. The tendency now is for hard rubber to be used only for those special applications where its particular properties are essential. The material has a heat resistance similar to Class B, and owing to the slow rate of production costs are relatively high.

(f) Cement-Asbestos Compounds.

Cement-asbestos compounds are usually made by mixing asbestos fibre with suitable binders, such as Portland cement, silica, lime or magnesia, with water as a medium. The mixture may be moulded into comparatively simple shapes and, after removal from the mould, allowed to set. This material is used mainly for arc-shields and separators.

Of these six classes, the plastics industry is

mainly concerned with classes (a) and (b), and to a minor degree with class (c). On this account, it is proposed to deal with these more exhaustively.

CLASS (a) HOT MOULDED THERMO-SETTING COMPOUNDS.

This class can be sub-divided into two groups :

(1) Phenol-formaldehyde products.
(2) Urea-formaldehyde products.

For many years before the commercial development of phenol-formaldehyde resins, chemists were aware of the formation of resinous products by the interaction of phenols and aldehydes, and it is of interest to note that, as long ago as 1872, Bayer published the results of his investigations in this field, announcing that the reaction between phenols and aldehyde is a general one, and that resinous bodies were produced. The commercial development of phenol-formaldehyde material, towards the end of the first decade of the present century, is associated with the name of Baekeland, and the product resulting from his investigations became known in its various forms as bakelite. During the early stages of this development, J. W. Aylesworth and L. V. Redman began the manufacture of related products under the names of Condensite and Redmanol respectively. After considerable controversy and litigation these interests were consolidated under the control of one concern. The technical advantages, both to the moulder and the customer, which these materials showed over those previously available, enabled them to be used with spectacular success in a great variety of ways. Such varied applications as the manufacture of telephone parts, radio components, ash trays, electrical accessories, containers and boxes—to mention only a few—brought the material before the public eye, and the commercial success acted as a powerful stimulus to the development of the plastics industry.

Fig. 2.—Old type of press formerly used with hand moulds.

The production of the moulding materials themselves is a very highly technical chemical process, and in consequence it is usually conducted by firms who specialize in powder making and do not engage in the actual manufacture of mouldings. The process of manufacture of the powder may be carried out in various ways, but is usually effected in two stages. By the interaction of phenol and formaldehyde a fusible, soluble resin is formed, and then dehydrated in the same reaction kettle. The resin is run out and allowed to set in pans. When cold, the resins are usually brittle and can be ground into powder form in readiness for the second stage of the process. This consists of mixing the resin with an anhydrous aldehyde hardening agent, such as hexamethylene tetramine, suitable fillers and colouring materials being added. For the bulk of the moulding powder produced, wood-flour is the most suitable filler. The actual process of mixing is usually done on hot mixing rolls, and during this operation the chemical reaction, or curing, is carried further. The extent to which this reaction is carried is very important, as it will affect the flow of the powder during moulding, a characteristic which is obviously of the utmost importance to the moulder. In consequence, the process must be carefully controlled by physical tests to determine the optimum time. The mixture is then thrown off the rolls and, after cooling, the sheets are broken up and ground into suitable form for moulding.

Of recent years, owing to the rise in price of

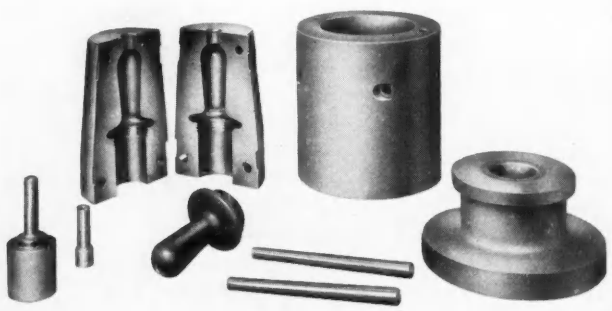


Fig. 3.—Various components of a hand mould.

phenol, its homologues, meta- and para-cresol, have been very extensively used in the manufacture of moulding powders.

As already mentioned, the standard grades of phenol-formaldehyde material have wood-flour as filler, but for special requirements, other fillers are used, *e.g.*, asbestos for heat resistance, and disintegrated fabric for shock resistance.

The actual moulding is done under heat and pressure. The required quantity of material, either in powder form or preformed into tablets, is charged into a highly polished mould, heated by steam, gas, or electricity to between 300° and 360°F., and placed in a suitable press, usually hydraulic. The press is then closed, causing the material to fuse and fill the cavity. The heat gives rise to a chemical reaction in the material, termed condensation, so that after an appropriate curing time when the press is opened the article is ejected in its final form, with a highly finished surface and in such a condition that it is not softened by heat. For small articles, a number of moulds or impressions are usually mounted in one press.

This process made possible the large scale production of complicated mouldings with a combination of dimensional accuracy, permanency of finish, resistance to heat and good electrical properties which could not previously be obtained in any other way, and the electrical industry was not slow to avail itself of the opportunities offered. In fact, it would be correct to say that the electrical industry has contributed largely to the development and success of the plastics industry.

Fig. 2 shows a press of the type in use in the early days of the industry, mainly with hand moulds such as that seen in fig. 3, while a modern 1,250-ton press used for radio cabinets and similar large articles is illustrated in fig. 4. For smaller work, the present practice is to mount a quantity of impressions in one press as already mentioned. A good example of this is shown in fig. 5, where a large number of impressions for making tumbler switch covers may be seen mounted in one press. It will be observed that these impressions are arranged to slide in and out of the press so that the loading of the press and the stripping of the the articles can be effected as speedily as possible and with the minimum of effort.

The phenolic materials, although of very wide application have decided limitations as regards colour, in that when made in the lighter shades they are not permanent. It was this fact, primarily, that led to the commercial development of the second class of thermo-setting compounds, the urea-formaldehyde plastics. In 1926, the first urea-type material appeared in this country, and immediately attracted the attention of the moulding industry on account of its colour properties. Articles could be produced in white, cream and pastel shades, which proved quite permanent in service, and the material quickly found a market in the electrical accessory field for making such articles as ceiling roses, switch covers and plates, etc. Gradually, further improvements were made in the material, and the expansion in production has been very rapid, due partly to the introduction of special grades of wood-filled urea powders which, as regards price, are better able to compete with the phenolic materials. The process of manufacture is akin to that for making the phenolic materials. The

Fig. 4.—Battery of modern 1,250-ton presses.

resin is prepared by the interaction of urea, thio-urea and formaldehyde, and the resulting product, a syrupy mass, is incorporated in a mixer with fibrous filler, wood-flour or paper pulp and the necessary pigments. The mixture is dried and ground to powder. Usually the material is supplied to the moulder either in a granulated or densified form, or preformed in tablets.

The actual conditions for moulding are slightly different from those required for phenolic materials. The same types of press and moulds are used, except that, on account of a tendency for this material to stain, it is desirable to use stainless steel or chromium plated moulds for the light colours. The moulding temperature is lower and must be carefully controlled, the actual temperature employed being between 240°F and 320°F, according to the nature of the job. The pressures required tend to be slightly higher, and the curing time longer. The mouldings are ejected hot, as is the case with phenolic mouldings, and in a highly polished condition. Wherever possible, in the case of urea mouldings, the necessity for machining operations such as drilling holes

Fig. 5.—Modern multi-impression mould.

should be avoided, but if absolutely unavoidable these can be performed provided special care is taken.

General Properties of Thermo-setting Materials.

Thermo-setting materials of both the phenolic and urea types, usually known as P.F. and U.F. respectively, yield mouldings which are light in density and very strong. They are also very stable, both being resistant to most chemicals and solvents, and far less liable to distortion due to age and damp than the majority of other materials. For example, wood in the course of time frequently distorts and cracks, but if due regard is paid to design, this does not occur with thermo-setting mouldings, even over a much wider range of temperature and humidity changes. This question of design will be dealt with more fully in the second part of this article. The materials are available in colours, the phenolic in the darker shades and the urea in all shades. As previously mentioned, the phenolic when made in the lighter shades are not light-fast and develop a yellowish tinge, whereas the urea are very rarely affected by prolonged exposure to light. Particulars of the more standard materials are shown in Table I.

The general characteristics are as follows :—

Specific Gravity.

This figure varies with the type of filler used and ranges from 1·35 to 1·6.

Tensile Strength.

Phenolic materials have a tensile of 6000/7500 lbs./sq. in. and urea 7000/9000 lbs./sq. in.

Cross-breaking Strength.

For phenolic 9000/11000 lbs./sq. in. For urea 11000 to 14000 lbs./sq. in.

Young's Modulus of Elasticity.

For phenolic materials, approximately 7×10^5

TABLE I.

Type	Filler	Resin	Colours available	Uses
General purposes (opaque)	Wood-flour	Phenolic and urea	Limited to darker shades for phenolic. Unlimited for urea.	All general purposes requiring average electrical properties.
Special electrical	Wood-flour	Phenolic and urea	Darker colours for phenolic. Black for urea.	All purposes where electrical requirements are above average.
Medium shock resisting	Cotton	Phenolic and urea	Darker colours	For mouldings requiring good impact strength.
High shock resisting	Fabric	Phenolic	Darker colours.	For highest impact strength.
Heat resisting	Mineral	Phenolic	Darker colours.	Where temperature conditions are above normal, up to 200°C.
Translucent	Paper	Urea	Unlimited.	General purposes.
Transparent	None	Urea	Unlimited.	Transparent effects.

lbs./sq. in.; for urea, approximately 10^6 lbs./sq. in.

Hardness.

By Brinell Test (125 kgm. on 5 mm. ball), for both types, 40–55.

Heat Resistance.

Standard grades of phenolic materials will not blister under 150/170°C., heat resisting grades under 200°C. The urea mouldings are not so good, and will blister if heated suddenly to much over 100°C. Both types are non-inflammable, but the standard phenolic will maintain combustion once it has been strongly ignited by an external source of heat. The urea type will not ignite. The plastic yield temperature of the urea type when tested in accordance with BSS.488 is approximately 100°C., that for phenolic being somewhat higher, ranging from 100°C. to 140°C. If maintained continuously at elevated temperatures under dry conditions, further condensation of the resin occurs with loss of water, and some shrinkage takes place. This tendency is more pronounced in the urea type and must be given careful consideration in the design of mouldings to be used at elevated temperatures.

Water Resistance.

Both types have quite good resistance to hot and cold water. If not strongly cured, the urea type will blister readily in boiling water, and, in practice, this is used to detect insufficiently cured mouldings. The water absorption on a standard disc at ordinary temperature in accordance with British Standard Specification No. 488 is: urea, 80 mgms. to 215 mgms., phenolic, 15 mgms. to 150 mgms., in 7 days; the figure for high shock resisting phenolic is 250 mgms. to 300 mgms. for 7 days.

Light Resistance.

Phenolic resins tend to darken with exposure to light, whereas urea resin remains water white. It was this property that first attracted interest to the urea resins, and the possibility of making light fast mouldings.

Resistance to Chemicals.

Both types are unaffected by all the usual solvents such as petrol, oil, alcohol, acetone, carbon tetrachloride, trichlorethylene, benzol and naphtha. Both are attacked by strong acids and alkalies. Weak acids and alkalies will affect the surface and destroy the polish gradually, the rapidity and degree of attack being dependent on the concentration and temperature.

Electrical Properties.

Both types are very good insulators, and the values for the principal electrical properties are :—

Surface Resistivity.

At ordinary temperature. As moulded, urea, $10^4 - 10^6$ megohms per cm^2; phenolic, $10^4 - 10^6$ megohms per cm^2. After 24 hrs. in water and wiping dry, urea, 10^3 to 10^5 megohms per cm^2; phenolic, $10^3 - 10^5$ megohms per cm^2.

Dielectric Strength.

At ordinary temperature, urea, 180 to 250 volts/mil; phenolic, 150/350 volts/mil. At 90°C., urea, 60 to 110 volts/mil; phenolic 30/250 volts/mil.

Dielectric Constant.

Urea, 6·0 to 9·0. Phenolic, 6·0 to 20·0

Power Factor.

At 800 cycles: urea, 5 to 10 per cent. Phenolic, 1·5 to 60 per cent.

In all the above figures a wide divergence in values will be noticed, but this covers the values for the various types of materials available.

Tracking.

There is a marked difference between the two types in their resistance to tracking. The phenolic types have been frequently criticised and held responsible for failures in service because tracking has occurred. The actual cause is usually that water condenses or collects on the surface together with dust or dirt, with the result that a leakage current passes over the surface, heat develops and builds up to the point where carbonization of the surface takes place, providing a conducting path, and a breakdown results. Frequently a little thought in design would have obviated the conditions conducive to tracking, and much of the blame for tracking failures which has been attributed to phenolic materials could justly be ascribed to bad design.

Considerable interest has been shown in the superior resistance to tracking of the urea types, which fail only under very severe conditions of ill-usage. Nevertheless, in all applications where the possibility of tracking is of great importance, the danger should, in the first instance, be minimised by careful design; after which the inherently better tracking properties of urea material should be weighed against the generally superior mechanical properties (except tensile strength) and lower cost of phenolic mouldings.

Summary of Physical Properties.

The principal characteristics of the main types of thermo-setting moulding material are set out in Table II. It must be mentioned that the figures given are based on standard test pieces of given

dimensions, and in view of the well-known difficulties involved in testing plastic materials, the greatest caution should be used in endeavouring to transpose these figures to other dimensions. As a guide for comparing one class of material with another, with a view to assessing their relative behaviour in service, the data given are invaluable.

Applications.

As already mentioned, the rapid growth of the plastics industry was due in the first place to the development of the phenolic materials, and in the second place, at a later date, to the development of the urea class. So far as the electrical industry is concerned, the most outstanding feature of the earlier days of this rapid growth was the application of these phenolic plastics to the manufacture of electric lighting and wiring accessories. In this the electrical industry undoubtedly contributed in no small measure to the further progress of the plastics industry, both by bringing these materials before the public, and by increasing demand making possible economies and price reductions on increased outputs.

The introduction of the urea plastics with their unlimited range of colour further contributed to this expansion, and with continual improvement in the materials available, the production of types for special purposes and the continuous progress in the technique of moulding, plastics steadily found applications in all branches of electrical engineering. At the present time, these applications include such a diversity of articles that it is possible to mention only a few, such as telephone sets, lampholders, ceiling roses, adaptors, starter panels, switch plates, plugs and sockets, radio cabinets, meter cases, magneto parts, distributor parts, lamp standards, vacuum cleaner and hair dryer parts, terminal strips and switch boxes. What the future developments in these classes of materials will be it is difficult to say, but every year shows marked advance in the technique of moulding, so that to-day mouldings are made which were impossible only a few years ago. Special types of these materials are continually being developed by the powder manufacturers for particular applications, so that continued expansion can be confidently anticipated. A survey of the process by which porcelain, metal and wood have been replaced by plastics indicates quite clearly, however, that the continuance of this trend at anything like the same pace, depends more on the cost of the materials themselves than on any other factor. As the plastics industry expanded during the last two decades, the cost of these thermo-setting materials was progressively reduced as output increased, but should this process of price reduction be arrested for any reason, it is quite possible that these thermo-setting materials may themselves be subjected to a measure of replacement by the newer synthetic thermo-plastic materials to be described in the second part of this article.

TABLE II.

	General purpose		Electrical		Medium shock resisting		High shock resisting	Heat resisting	Translucent
	Phenolic	**Urea**	**Phenolic**	**Urea**	**Phenolic**	**Urea**	**Phenolic**	**Phenolic**	**Urea**
Moulding shrinkage inch/inch	.005—.008	.007—.010	.004—.007	.007—.010	.004—.006	.003—.006	.003—.005	.002—.006	.008—.010
Specific gravity	1.35—1.40	1.5—1.6	1.35—1.40	1.45—1.52	1.35—1.38	1.50	1.37	1.7—2.1	1.50—1.60
Tensile strength .. lbs./sq. in.	5500—7500	7000—10000	6500—7500	7500—10000	5500—8000	6000—8000	6000—7000	3500—5500	8000—10000
Cross-breaking strength lbs./sq. in.	8300—11000	11000—14000	10000—11000	11000—14000	7500—11000	8300—10000	12000—14000	6000—8000	11000—14000
Impact strength B.S.S.771 ft./lbs.	.16—.22	.14—.24	.17—.22	.17—.22	.30—.37	.34—.40	1.0—1.5	.08—.22	.20—.30
Young's Modulus of Elasticity lbs./sq. in.	$6.2–7.8\times10^5$	10^6	$6–7\times10^5$	$10^5–10^6$	$5.5–6.5\times10^5$	—	$6.0–7.0\times10^5$	$7.5–9.5\times10^5$	$10^5–10^6$
Hardness, Brinell B.S.240	40—45	40—55	43—47	40—50	43—47	40—50	35—40	55—70	40—55
Power factor .. 800 cycles	10—40%	5—10%	3—4%	—	10—25%	—	15—40%	10—20%	—
Vol. resistivity at 20°C. megohms/cm³	$10^5–10^6$	$10^5–10^6$	$5–10\times10^6$	$10^5–10^6$	$10^5–10^6$	$10^5–10^6$	$10^4–10^5$	$10^5–10^6$	$10^5–10^6$
Surface resistivity at 20°C. megohms/cm²									
(a) as moulded	$10^4–10^5$	$10^4–10^5$	$1–5\times10^6$	$10^5–10^6$	$10^4–10^5$	$10^4–10^5$	$10^3–10^4$	$10^4–10^6$	$10^4–10^6$
(b) after 24 hours in water ..	$10^3–10^4$	$10^3–10^4$	$10^4–10^5$	$10^3–10^4$	$10^3–10^4$	$10^3–10^4$	$10^2–10^3$	$10^4–10^6$	$10^3–10^4$
Dielectric Strength									
(a) 20°C. .. .. V/mil	150—250	180—250	300—350	180—250	180—250	180—250	125—175	150—250	180—250
(b) 90°C. .. .. V/mil	30—150	60—80	200—250	70—90	40—80	70—90	20—50	70—180	60—80
Moisture absorption (B.S.S.488) mgms.	90—140	80—195	90—150	120—195	110—130	180—215	250—300	15—50	80—150
Specific inductive capacity ..	6.5—9.0	6.0—9.0	5.8—6.5	6—7	6.5—8.0	6—7	6.5—10	8—20	6.0—9.0

These figures are derived from tests on standard test pieces of the more general types of materials. Special materials have been developed for many particular applications where certain properties are required to be highly developed, such as water resistance, acid and alkali resistance, anti-tracking properties, low loss properties and flexibility.

(*To be continued*)

The Electrical Equipment of Trinidad Paper Pulp Mill.

By J. F. PRINCE,
Export Sales Dept., G.E.C. Engineering Works, Witton.

Bamboo is particularly well suited to the production of printing and writing papers, but it was not until comparatively recently that a satisfactory process was evolved for achieving this object.

The article deals with the process adopted at a Trinidad paper mill which is wholly electrified. A description is given of the machinery employed and the electrical equipment installed which includes generating plant, mill motors and control gear, distribution switchgear, cabling and lighting fittings.

Fig. 1.—General view of Trinidad Paper Pulp Mill.

Fig. 2.—One of the avenues through the Bamboo Plantation.

INTRODUCTORY.

THE production of paper from bamboo is a very ancient process, for the Chinese were engaged in the task long before the inhabitants of Britain had any use for paper. The Chinese laid bamboo stems in pits in the ground and covered them with lime, allowing the stems to rot for several months. They were then washed and beaten by hand into a pulp, which was bleached in the sun. After further washing and hand beating it was made into sheets of paper by hand.

About 40 years ago experiments were started with the object of making paper from bamboo by machinery, for bamboo is one of the best fibres available for the production of printing and writing papers. It was not until 1912, however, that success was achieved. James Bertram & Son, Ltd., Leith Walk, Edinburgh, then built a mill in China to produce 5,000 tons per annum of bamboo pulp. In 1919, this firm also built a paper mill in India to make printing and writing papers from bamboo, and a few years later the capacity of the plant was doubled. Since then two further mills in India, namely Titaghur Paper Mills and Bengal Paper Mills, have been equipped for converting bamboo into paper.

About the year 1914, Thomas Nelson & Son, Ltd., of Edinburgh, purchased an estate in Trinidad, British West Indies. It is situated about 6 miles from Port of Spain amidst beautiful surroundings. In due

course 1,000 acres were planted with bamboo. This is believed to be the first occasion on which bamboo was planted specifically for the purpose of paper production. A view down one of the avenues of the plantation is shown at fig. 2. Eventually in 1935, it was decided to erect a mill on the estate with a view to converting the bamboo into paper pulp. The mill entered production about two years ago, and is capable of a weekly production of 100 tons of easy bleaching pulp of high quality.

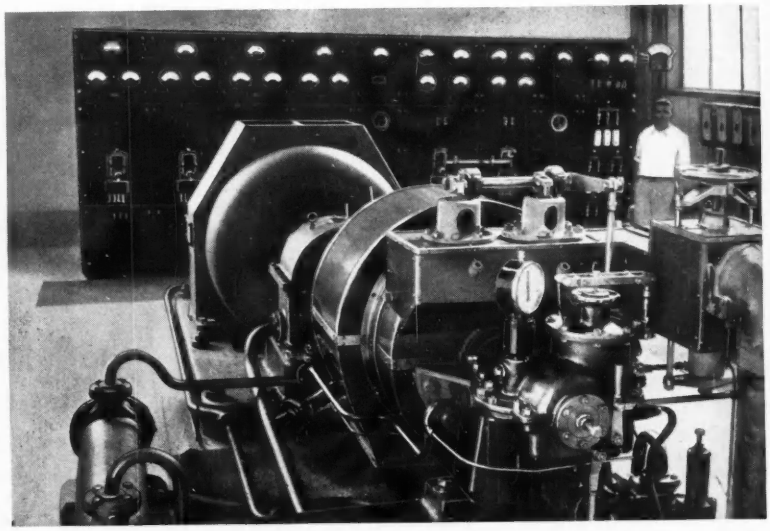


Fig. 4.—View in the Power House showing main generating set from the turbine end, with switchboard in the background.

LAYOUT OF BUILDINGS.

A general view of the mill buildings is shown in fig. 1, and their general layout is given in the plan reproduced in fig. 6. It may be noted from this plan that in addition to the main mill, the principal buildings include

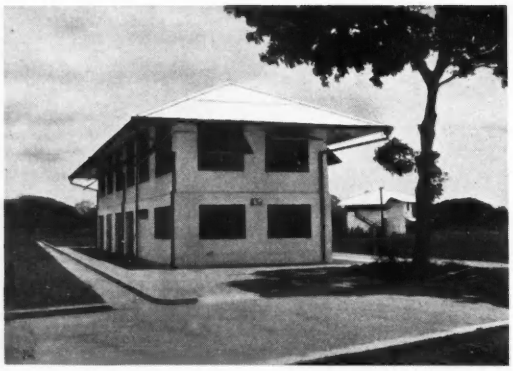


Fig. 3.—Administration offices, with residential quarters in the background.

boiler house and power house, engineers' maintenance and repair shops, and an acid making plant with adjacent chemical store. A 24-foot roadway and railway sidings running into the buildings afford excellent transport facilities to Port of Spain.

In addition to the buildings shown on the plan, administrative offices, fig. 3, are situated on an adjoining part of the estate, also residential quarters which can be seen in the background of this illustration. A pump house to provide the large quantity of water required in manufacture is situated on the San Juan River, about a quarter of a mile from the mill.

MILL EQUIPMENT.

At first glance it might appear that bamboo would be an ideal material for conversion to paper pulp, as it is easy to handle and shred, but in practice there are many manufacturing difficulties, so that its treatment demands great care and, in addition, the processes employed involve a close degree of regulation. It follows that the equipment of the mill must consist of highly specialised machinery.

The principal sections of the equipment are the bamboo crusher controlled by hydraulic pressure, acid making plant, acid storage tanks, digesters, machine stuff chest, strainers, the main paper pulp machine, cutter, hydraulic baling press and weighing machine. To this list should be added many items of elevating and conveying plant. Electric power is used throughout the mill, and the complete electrification scheme

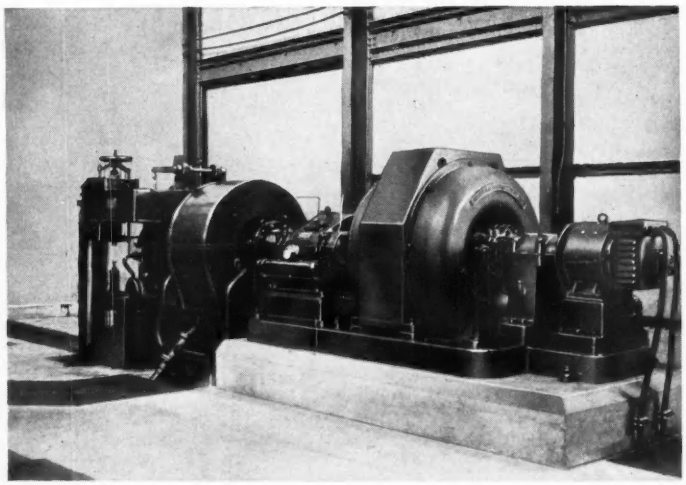


Fig. 5.—The 500 kVA geared turbo set from the alternator end.

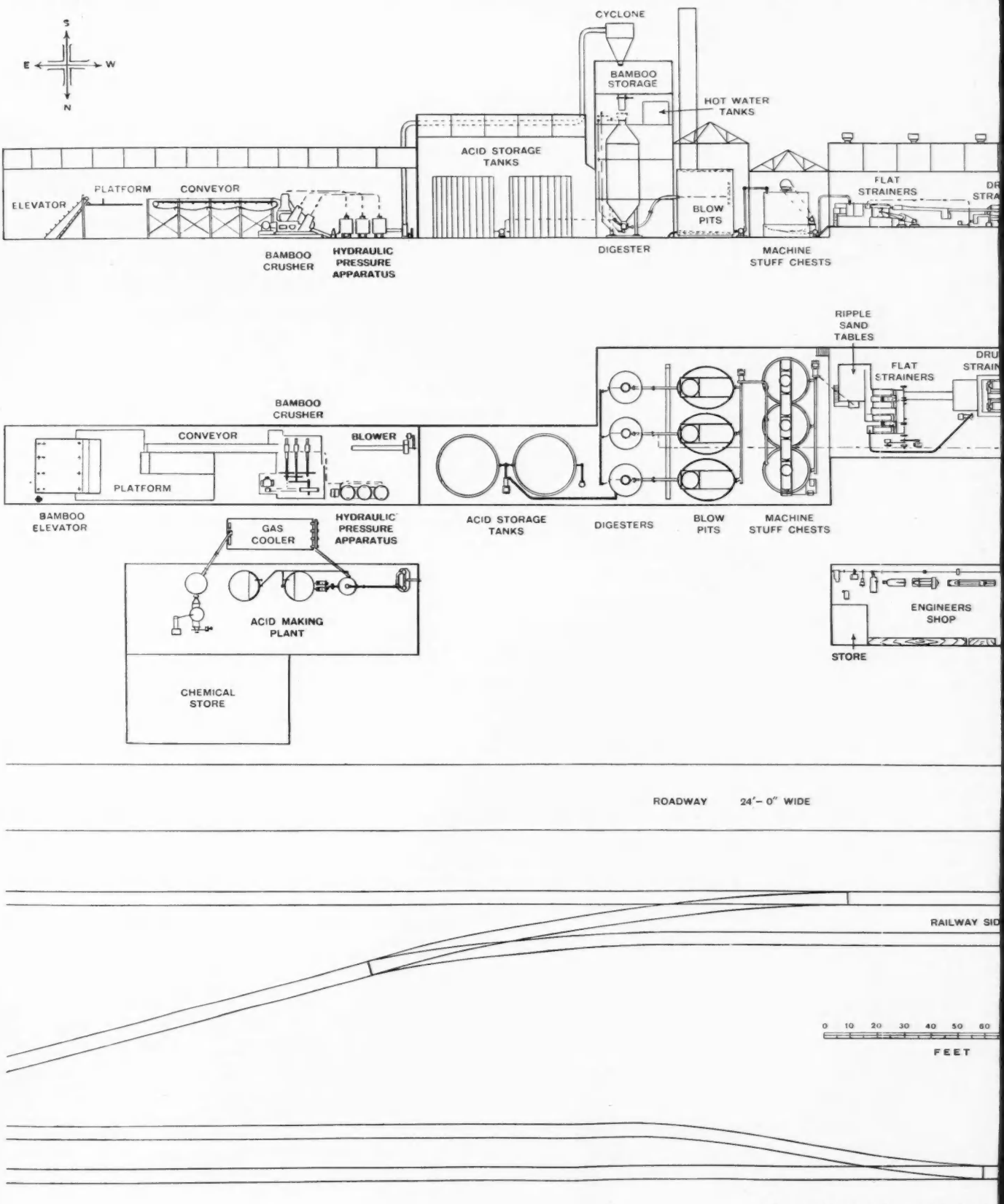
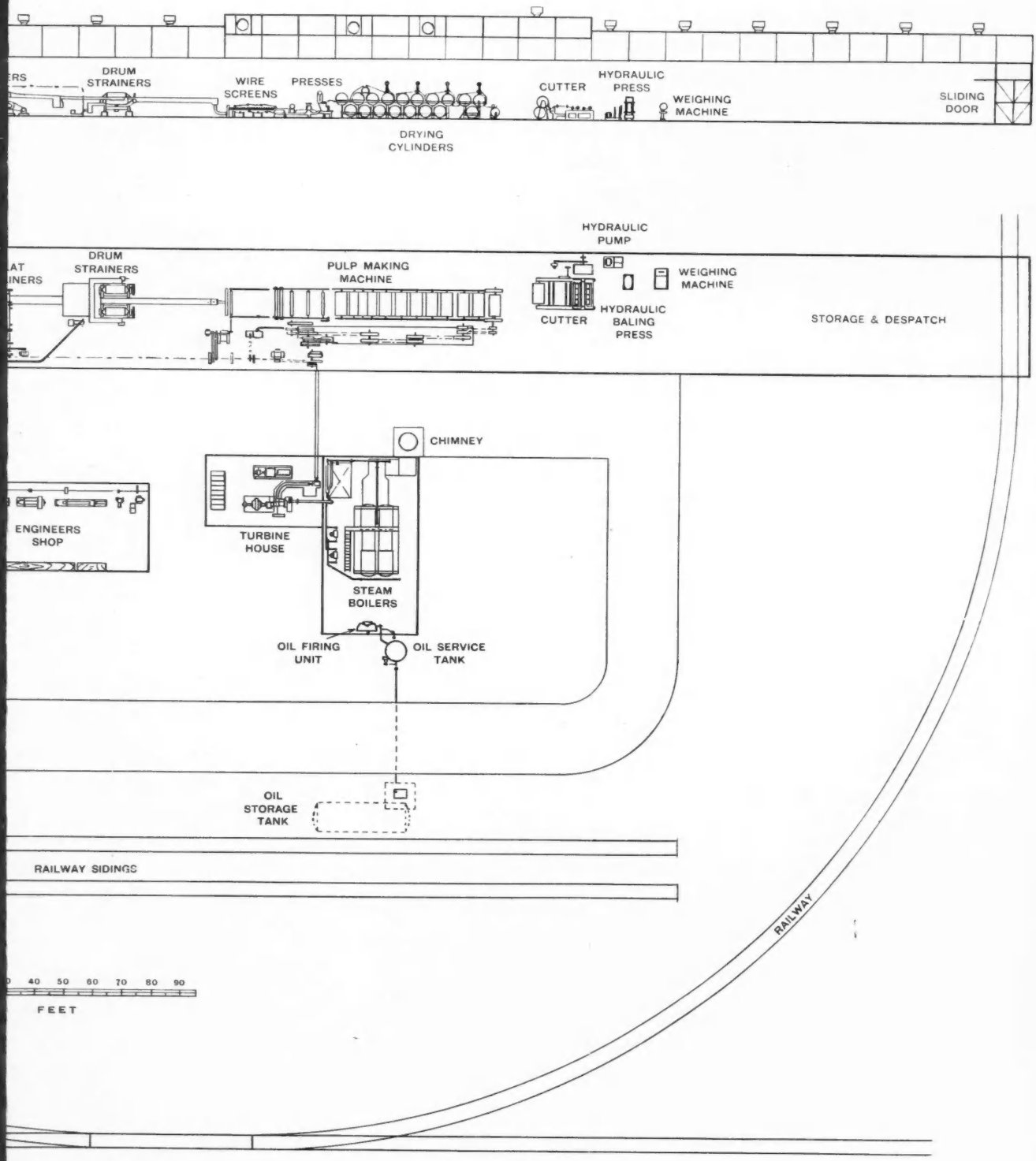


Fig. 6—General layout of the M



out of the Mill Buildings.

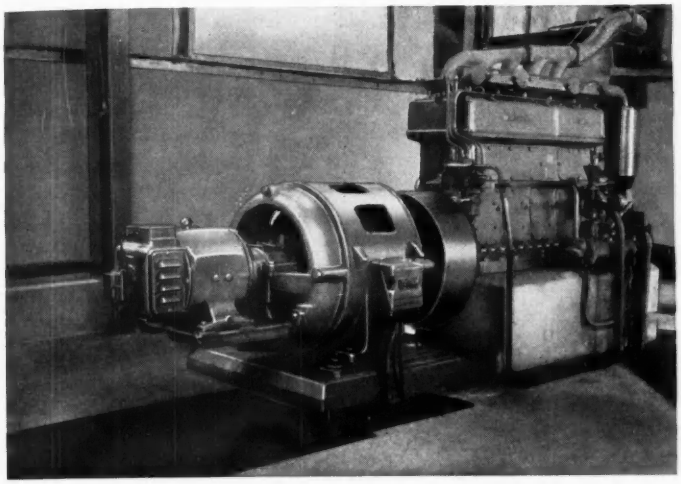


Fig. 7.—50 kVA stand-by oil engine driven alternator.

was entrusted to the G.E.C., who manufactured and installed the power house plant and switchgear, motors for driving the mill equipment and pumping plant, motor control gear, distribution switchgear, lighting fittings and lamps, and cable consisting of paper insulated lead covered and armoured power cables, V.I.R. lighting cable and hard drawn bare copper wire for use as transmission lines from the power house to the pumping station, administration buildings and residential quarters.

The mill equipment was supplied by James Bertram & Son, Ltd. The electrical equipment was forwarded to this company's works and the whole of the plant for the scheme was tested and co-ordinated prior to shipment. This greatly facilitated erection work on site.

POWER SUPPLY AND DISTRIBUTION.

The main power supply is from a 500 kVA geared turbo-alternator, figs. 4 and 5. The turbine runs at a speed of 6,000 r.p.m. and the alternator at 1,800 r.p.m., the supply being 440 volts, 3 phase, 60 cycles. For week-end purposes a 50 kVA oil engine driven alternator, fig. 7, has been installed.

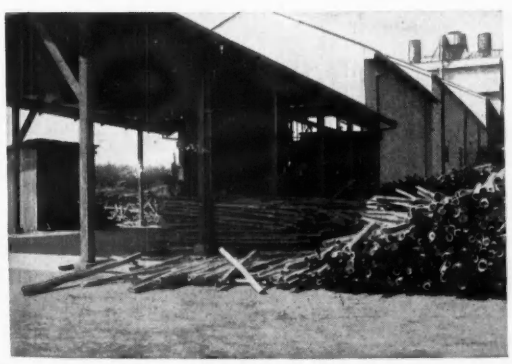


Fig. 8.—Cut bamboo ready for passing into the mill.

Both the alternators are controlled from the 9-panel main switchboard shown in the background of fig. 4. For each machine there is provided a main control panel and a regulator panel. Four of the other panels control feeder circuits, while the ninth is equipped with automatic voltage regulating equipment.

Distribution is by means of iron-clad panels situated at convenient points in the factory. Paper insulated lead covered and armoured cable is used both from the power house to the distribution boards, and also for connection to motors and starters.

PAPER PULP PRODUCTION.

In view of diseases to which bamboo is subject it is very important that, when used for the production of paper pulp, it should be cut at the right time. After cutting, it has to be well dried before use, and at the same time kept free from attack by insects which may play havoc rapidly with a pile of drying bamboo. Stacked bamboo at the intake end of the mill is seen in fig. 8. The mill is arranged on the continuous process method, the bamboo entering at one end of the mill and emerging as

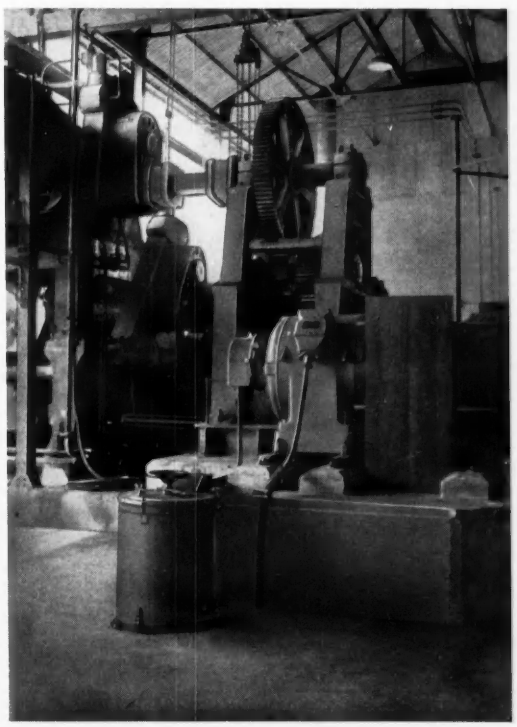


Fig. 9.—Bamboo crusher driven by 175 h.p., 700 r.p.m. slipring motor controlled by oil immersed rotor starter panel.

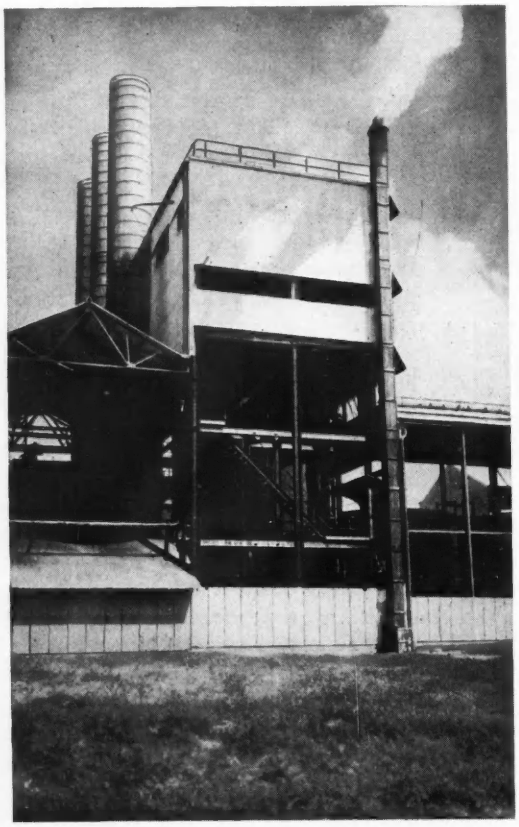


Fig. 10.—The Digester House.

finished sheets of pulp at the other; this feature is at once evident from the layout plan at fig. 6.

The bamboo is conveyed first to a crusher driven through a vee-belt and gearing by a 175 h.p. 700 r.p.m. slipring motor controlled from an oil immersed rotor starter, fig. 9. The crusher is of a special design, generally on the lines of a sugar crusher. It comprises a series of rollers which crush and break the bamboo into pieces about 2ins. in length and well split up. These pieces, referred to as chips, drop on to a vibrating screen which extracts part of the dust adhering to them. They are then blown to a cyclone housed on the top of the digester buildings, fig. 10, at a height of about 80 feet.

The chips are fed next to digesters in which they are cooked with acid and steam at a pressure of about 90 lbs. per sq. inch.

The digesters have a capacity of about 12 tons and are built of $1\frac{1}{4}$ inch steel plates lined with acid resisting brick. Special pressure and temperature recorders form a part of the digester equipment, all valves and pipe fittings being made from acid resisting steel. The necessary boiling mixtures for the digesters are prepared in the acid making plant, connection from which to the digesters is by means of acid resisting pipe and fittings.

After treatment in the digester, the contents are blown by pressure into large wooden vats or blow pits where the spent acid is thoroughly washed out and in due course the digested bamboo or pulp, which now resembles porridge, is pumped to the machine stuff chests and kept in constant agitation. Thence the pulp is taken to the main mill room, fig. 11. It is diluted with clean water to a consistency of about 99 per cent and run by gravity over a series of sand tables and strainers, fig. 14, so as to eliminate as much foreign matter as possible, through a washing plant, then on to the pulp making machine, figs. 12 and 13.

The pulp making machine follows the general principles of the paper making machine. The pulp

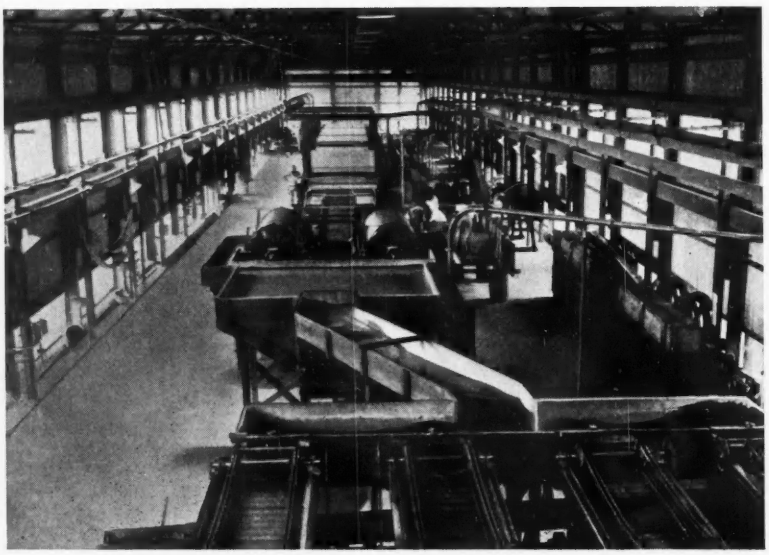


Fig. 11.—General view of the main mill room.

is fed first on to a continuous fine wire mesh screen, where initially the water is gradually drawn off by natural drainage, and then removed by vacuum until the pulp has sufficient consistency to enable it to be taken from the wire screen on to endless woollen felt bands.

Once on the felt bands the pulp, which is now in one continuous sheet, is pressed between two sets of large brass rollers; this process extracts a large amount of water. The pulp is then taken over a series of steam heated cylinders, where the remaining moisture is gradually evaporated. At the end of the machine the dry pulp is wound on steel rollers, then passed to the cutting machine where it is cut to suitable sizes. Finally it is baled and packed under hydraulic pressure for shipment. The pulp, which is unbleached, is of a light grey colour and after cutting resembles thick sheets of blotting paper.

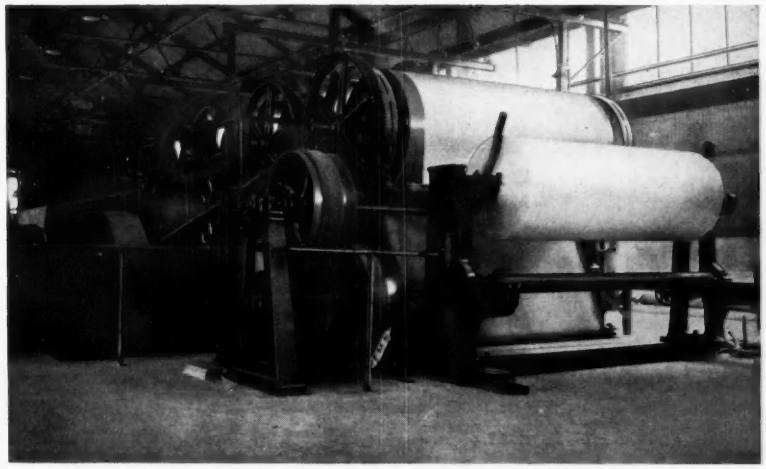


Fig. 13.—Delivery end of the paper pulp mill.

The rolls of the paper machine are driven through belting by a 60 h.p. 700/250 r.p.m. slipring motor controlled from an oil switch and drum controller. The slipring motor driving the cutting machine is rated at 9 h.p. 1,140/380 r.p.m., and is controlled from a contactor switch and rotor regulator. Reference individually to the many other motors in the mill is unnecessary. They are of the protected or drip-proof type according to their situation in the mill. The control of the slipring motors is by oil immersed rotor panels, while the squirrel cage motors are controlled in some cases by star delta starters, and in others by direct to line starters.

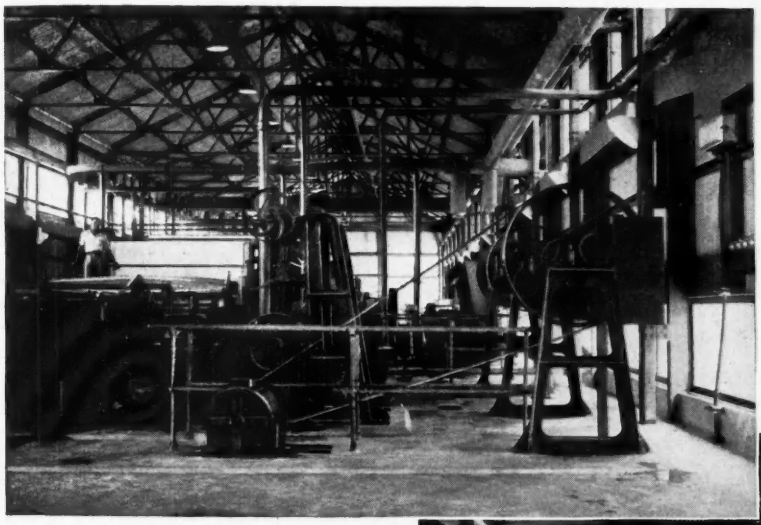


Fig. 12.—The feed end of the drying cylinders with the 60 h.p. slipring induction motor which drives the cylinders.

MAIN PUMPING EQUIPMENT.

The pump house on the San Juan river contains two main pumps, one of 30,000 and the other

Fig. 14.—East end of the main mill room with electrically driven strainers.

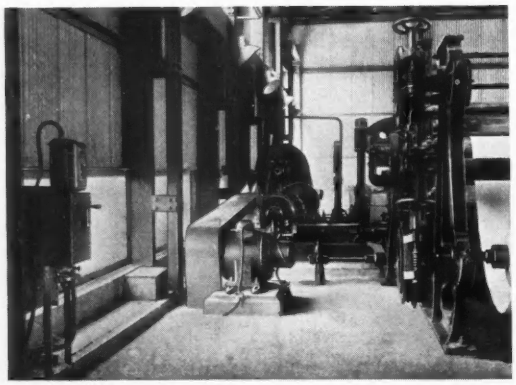


Fig. 15.—West end of the main mill room with 9 h.p. 1140/380 r.p.m. slipring motor driving cutting machine.

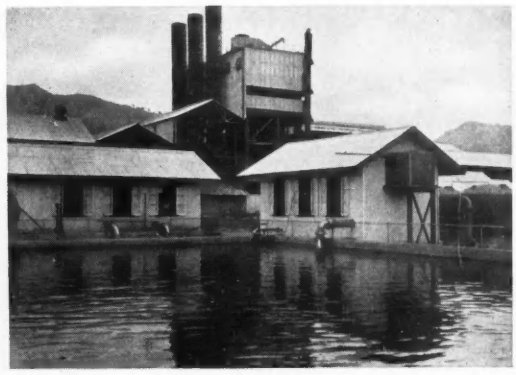


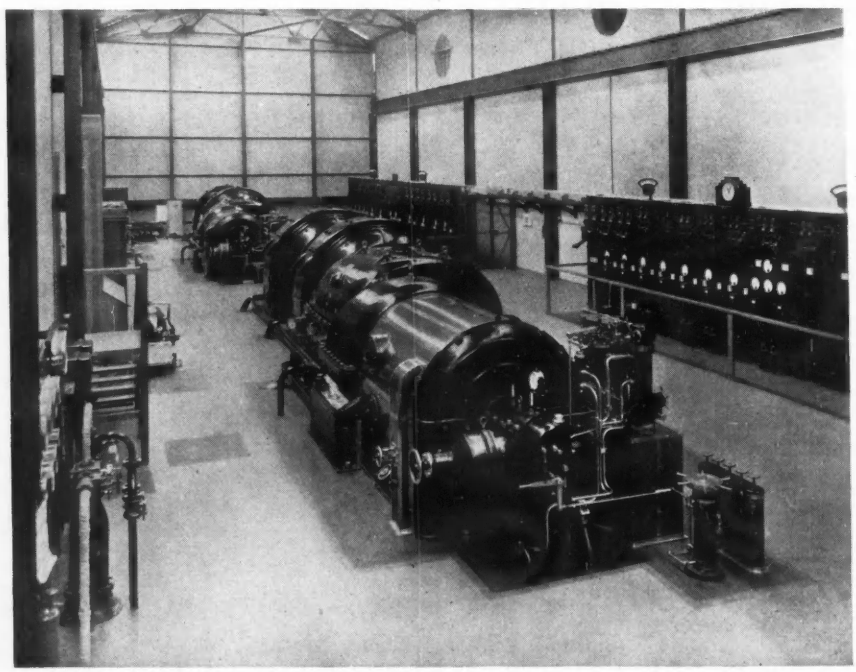
Fig. 16.—Water reservoir with pump house and water strainers.

of 50,000 gallons per hour capacity. The slipring motors which drive them are rated respectively at 25 h.p. and 45 h.p. An auxiliary pump driven by a double cylinder Diesel engine is also installed in the pump house.

The water is stored in a large concrete tank near the factory buildings, fig. 16, and from there it is passed through filters into a smaller tank and delivered to the factory by means of electrically driven high and low pressure pumps. The factory is also equipped with a water softening plant.

The author is greatly indebted to G. D. Smooker, Esq., Managing Director of the Trinidad Paper Pulp Mill for permission to publish the foregoing information and illustrations, and also to Thos. Nelson & Sons, Ltd., and James Bertram & Son, Ltd., for technical and other information relating to the manufacture of the pulp and the operation of the plant.

G.E.C. Turbo Plant for Paper Mill Supply



Two 5,000 kW 3,000/500 r.p.m. G.E.C. Fraser & Chalmers geared turbo-generator sets recently put into service in the power house at the Aylesford Paper Mills of Albert E. Reed & Co., Ltd. Each set comprises two 2,500 kW D.C. generators coupled in tandem.

A Unidirectional System for the Lighting of Double-Carriageway and One-Way Roads.

By J. G. CHRISTOPHER,
G.E.C. Exterior Lighting Dept.;
J. B. SMYTH, B.Sc., and J. M. WALDRAM, B.Sc., F.Inst.P.,
G.E.C. Research Laboratories, Wembley, England.

The problems involved in lighting an ordinary road, in which traffic moves in both directions, are complicated by various conflicting requirements. Recent study of the action of street lighting has shown how such difficulties can be avoided on both double-carriageway and one-way roads, and the way in which they can be illuminated more economically and efficiently than by the conventional systems now in use for lighting the normal two-way carriageway.

PRINCIPLES.

EXPERIMENTS have shown[1] that the light from a street lantern is reflected from normal street surfaces in rather unexpected and preferential ways. The usual smoothing action of the traffic is sufficient to make road surfaces behave very differently from matt surfaces at the angles of reflection and view which generally occur. One consequence of this is that each lantern produces on the road surface a bright T-shaped area which does not extend beyond the lantern to the side away from the observer. In an attempt to correct this, certain earlier lanterns were designed with a distribution of light which was more concentrated in the direction away from the oncoming traffic[2]; but experience showed that the effects of the road surfaces generally met with were too powerful to be usefully influenced by such means.

The light which any lantern emits in directions away from the observer is practically useless, so far as that observer is concerned, in making the carriageway bright. It may contribute to a certain extent towards making the footpaths and surrounds bright, but even these surfaces, which are not subject to traffic wear, are sufficiently far from being matt for the contribution to be small.

Now in a normal road, the light emitted away from an observer facing in one direction is directed towards an observer facing in the opposite direction, and is consequently useful. If the side of a lantern facing the traffic on its own side of the road is called the "facing side," and the back of the lantern the "trailing side," then it can be seen from fig. 1 that in a normal installation the facing sides of the lanterns are responsible for illuminating the near side of the road, and the trailing sides are responsible for the off side; this is true for both directions of traffic.

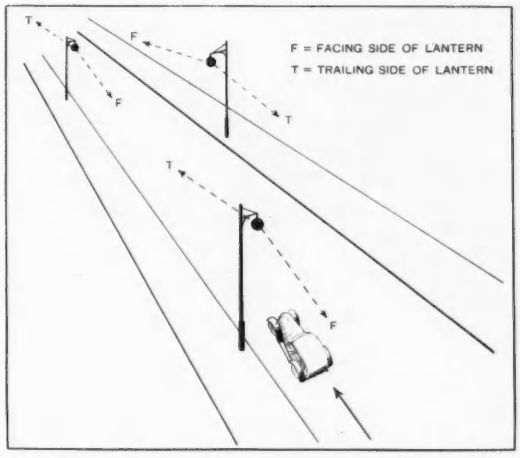


Fig. 1.—Diagram of two-way street indicating the direction of lighting in a normal installation.

If, then, a conventional system is used for a one-way road, it will be clear that half of the light emitted by the lanterns is wasted. Light from the trailing side of the near side lanterns and the facing side of the off side lanterns is directed away from the oncoming traffic, and is of very little use in making the carriageway bright. Such a system is therefore unnecessarily wasteful; and there are also further disadvantages. For although the light directed away from the traffic is of little use in lighting up the road, it is only too effective in illuminating and making bright any objects on the road, vertical edges of kerbs at road junctions and other features. This is a disadvantage, for, as is well known, such things are seen as dark silhouettes against the brighter background of the road surface and other surrounds; it is therefore the object of the lighting to make the background surfaces bright, while avoiding the illumination of any objects, kerbs or other important shadows. In a normal two-way road this is difficult to avoid completely, for the light which makes the background bright for traffic in one direction makes the objects bright for traffic in the other direction: in a one-way carriageway it is possible to produce much better results, as will be shown. In

double-carriageway roads a further disadvantage exists, for, in order to light such roads effectively, it is generally necessary to illuminate each carriageway separately[3], and therefore to provide a double lighting system. The result is that with conventional lanterns four rows of light sources can be seen, and

Fig. 2.—Complete installation of Uniway lanterns using 125W H.P.M.V. lamps on Great Chertsey Road.

the view presented to the road user contains a confusing array of lanterns which makes the scene difficult to "read" and renders driving unnecessarily uncomfortable.

The unidirectional system of lighting double-carriageway and one-way roads provides a normal light distribution in the direction facing the traffic, but in the other direction the light is entirely obscured. This is the converse of several systems which have been attempted—including the "bi-asymmetric" distribution referred to above, which was used in some early lanterns for high-pressure mercury vapour discharge lamps—in which the greater part, or all, of the light is directed *with* the traffic, in the manner of headlights. Such systems are generally tried in order to reduce glare, and in this they usually succeed. However, when the light is cut off on the facing side the effectiveness of the system is very poor since the brightness of the road becomes quite low, especially in wet weather, as motorists who have used headlights will know. In addition, the revealing power is rendered particularly low and the appearance deceptive owing to the high illumination of the objects.

The unidirectional principle has several advantages: first, it is possible to produce a given result with half the power of a normal installation, since the flux usually directed away from the traffic can now be used in the direction facing it. For another reason explained below, a further gain can be achieved, and it has been possible with 125W. H.P.M.V. lamps to produce a result equal to that usually obtained with 400W. lamps; an effect very little inferior has actually been obtained with 80W. H.P.M.V. lamps. This is of great importance for the lighting of double-carriageway roads in outlying districts where energy and distribution are expensive.

Second, the revealing power is much better than that of a normal installation.[4] Light coloured objects, such as pedestrians or cyclists in light macintoshes, which ordinarily tend to merge with the background, appear as hard black silhouettes in all positions, there being no "flash-up" of such objects as they pass a lantern. Fig. 2 shows a photograph with two pedestrians placed at the position at which, in a normal installation, they would be most illuminated—about 30ft. behind a lantern. One pedestrian is wearing a very dark coat (reflection factor 1·5 per cent) and the other a light macintosh with a reflection factor of slightly less than 10 per cent. About 75 per cent of pedestrians are darker than this.[5] Both objects appear as hard dark silhouettes, and it is difficult to detect which is wearing the light coat.

The third advantage is that in double-carriageway roads the second carriageway seems to be entirely unlighted. The lanterns themselves can be located only with difficulty on a clear night, and it is hard to believe that there is any light on the other carriageway at all. Consequently drivers are not troubled by the glare and confusion of the lamps on the other carriageway, and at the beginning of double-carriageway sections they are led naturally on to their proper carriageway with less danger of colliding with the end of the central reservation. This effect is so marked that during the first trials on a public street the responsible electrical engineer, approaching the test section for the first time, thought that the supply had failed in one carriageway.

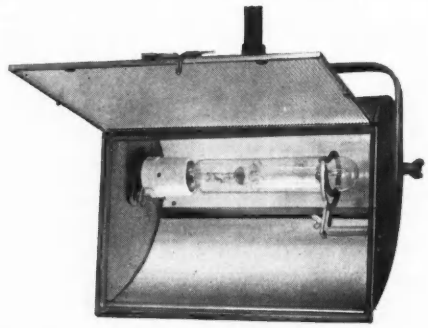


Fig. 3.—Experimental unidirectional lantern for 250W H.P.M.V. lamps.

A fourth advantage, less important perhaps than the others, is the clearness with which road junctions are revealed. Such junctions are often difficult to see, frequently being indicated only by the edge of the kerb of the side road which shows as a dark line crossing the footpath if the lanterns are well placed, or by the returns of buildings and fences which may serve to reveal a side road if they show as a dark interruption to the line of the buildings and fences in the main road. In a normal system this occurs when the lanterns are well placed with respect to the junction, but other considerations may prevent the optimum location of lanterns from this point of view; in any case the edges of the kerbs and the returns of buildings are always illuminated to some extent by light emitted in the direction of the traffic. In the unidirectional system such light is cut off, and the junctions are therefore always better revealed than in a normal system. It has, in fact, been shown by model experiments that if a second similar system is added, working in the reverse direction, so that the combination of the two makes a conventional two-way system using twice the power, the appearance and "visibility" in the road deteriorate, and objects and junctions are less well revealed.

The glare from the lanterns is, of course, the same as is generally associated with a good non-cutoff installation, without the extra glare from the other carriageway. It is hoped to apply the principle to a system having a normal cutoff distribution on the facing side, the candlepower being cut off above 75° from the downward vertical, with a complete cutoff on the reverse side. Such an installation would, of course, require short spacing per row of lanterns (thereby increasing the cost), but would probably provide ideal lighting for double-carriageway roads. It would have all the advantages of the cutoff system in respect of complete absence of glare, together with high revealing power and low power consumption.

DEVELOPMENT OF SUITABLE LANTERNS.

The principles of the unidirectional system were originally checked by experiments on a model of a one-way street, from which some of the above conclusions were first drawn. For trials on actual roads, the first full-size experimental lanterns employed trough reflectors and horizontally burning 250W. H.P.M.V. lamps, as illustrated in fig. 3.

The first test was made on a single carriageway running through the G.E.C. Wembley estate, but the results were not very encouraging as the surface of this road, due to the absence of high speed traffic, had reflection characteristics very different from those found in normal thoroughfares. It was therefore decided to make a further trial on a public road, and the experimental 250W. H.P.M.V. lanterns were erected on the Great Chertsey Road near Twickenham. This is a double-carriageway road, running through open country and surfaced with two-coat hot-pressed asphalt, a very common surface in Middlesex. The lanterns were mounted 25ft. above the ground, on existing poles at about 190ft. staggered spacing. It was at once obvious that a very great improvement over the first installation at Wembley had been obtained. The expected results were achieved: the revealing power of the installation was high, the silhouette effect being maintained even when objects were very light in colour; and the benefit from the apparent absence of lanterns on the far carriageway was most noticeable.

Fig. 4.—Early installation of experimental unidirectional lanterns shown in fig. 3, using 250W. H.P.M.V. lamps (on nearside carriageway only).

Fig. 4 shows the appearance of the roadway, and clearly indicates the satisfactory road appearance which was attained. The appearance of the drivers' carriageway was approximately equal to that normally obtained in an installation using 400W. H.P.M.V. lamps. Some possible improvements in design were, however, evident. With 250W. lamps the maximum candlepower is high, and when the installation was first erected some discomfort glare was present; this was reduced by fitting a more diffusing front glass to the lantern, whereby the maximum candlepower was decreased. It was, however, noticeable that the wide spread of light in azimuth, which was a natural consequence of the type of lantern employed, was serving no useful purpose, as the light falling on the fields adjoining the roadway was wasted. Some light also fell on the other carriageway and reduced the silhouette effect.

A lantern projecting light in one direction has, in principle, an advantage over a normal lantern. When a lantern emits two beams of light up and down the road, it cannot be usefully rotated in azimuth on bends so as to send one beam down the road without sending the other beam off the road. Consequently the width of the main beams must be made greater than is necessary for a straight road in order to cover the positions in which the lantern is mounted on the outside of a bend. This entails more light in the beam and eventually a larger lamp. On the other hand, a lantern having only one beam can always be rotated to direct this beam to the best advantage on bends; consequently the beam can be made narrower, and a smaller lamp can be used to achieve the same result. It is this consideration, together with the possibility of using the back light in the facing beam, which has permitted such drastic reduction in power in the lantern finally designed.

DESIGN OF AN EFFICIENT LANTERN FOR UNIDIRECTIONAL LIGHTING.

As a result of these experiments it was possible to proceed with the design of a more efficient lantern suited to the special requirements of this form of lighting. Provided that little light is allowed to fall beyond the limits of the road and footpaths, the light output of the 125W. H.P.M.V. lamp is ample to provide, on the carriageway itself, the intensities usually associated with a 400W. H.P.M.V.

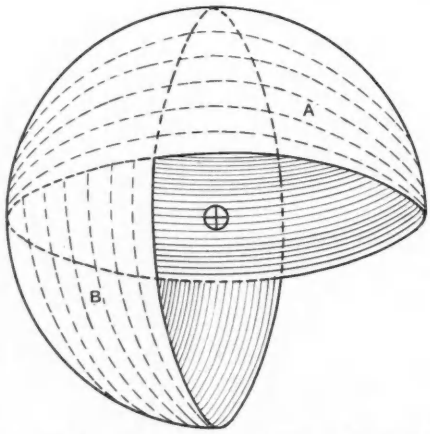


Fig. 5.—Diagram illustrating zones over which light can be collected and redirected.

lamp. In addition, the small light source of the 125W. H.P.M.V. lamp lends itself to a design in which the necessary concentration of light can be obtained.

If the lamp is assumed to be placed at the centre of a sphere (fig. 5), the flux falling on the upper hemisphere *A* and the back lower quarter sphere *B* can be redirected, the front lower quarter sphere being left open to permit the emergence of the light upon the road. Calculation and experiment showed that the flux falling on the back lower quarter sphere was sufficient to provide the main beam, while the light falling on the upper hemisphere, together with the direct light from the lamp, could provide the necessary distribution from vertically below the lantern up to the main beam. Consideration of the geometry of the roadway relative to the lantern shows that the angle subtended at the lantern by the width of the road, and thus the necessary spread of light across the road, will be greatest in directions vertically downwards, and will decrease as the angle to the vertical increases. This factor governs the contour of the reflector in the upper hemisphere.

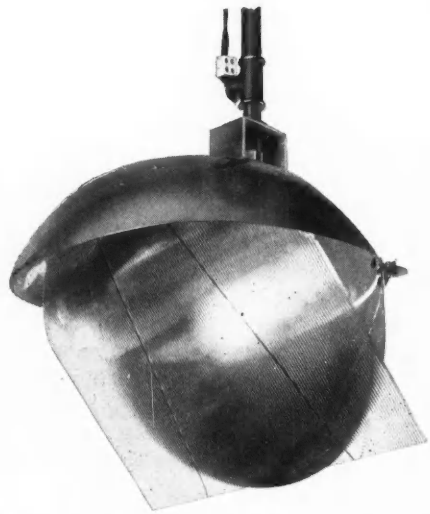


Fig. 6.—Experimental model of Uniway lantern.

The general arrangement of the unit may therefore take the following form: the main beam is provided by a paraboloidal reflector below and behind the lamp, the intensity distribution in azimuth of this beam being controlled by a fluted glass closing the mouth of the lantern. This combination also provides a large flashed area which is desirable in order both to reduce discomfort glare and to enhance the appearance of the lantern at night. The hemisphere above the lamp is occupied by a reflector having a contour designed to direct light into regions from below the main beam down to the vertical, the side-spread increasing as the direction approaches the vertical.

An experimental lantern was constructed on these lines using two separate reflectors of polished aluminium combined with a fluted glass to give the necessary diffusion and spread in azimuth. The contours of the reflectors were modified until a suitable distribution had been obtained. This experimental lantern may be seen in fig. 6 which shows the separate reflectors and front glass.

MECHANICAL CONSTRUCTION.

The mechanical design of the lantern had to fulfil the following conditions :—

1. The lantern should be totally enclosed and non-ventilated in order to reduce maintenance and to enable its initial performance to be retained over long periods.

Fig. 7.—Standard Uniway lantern.

2. Side bracket entry, already made popular by the Difractor bowl lantern, should be employed for ease of erection.
3. In order to combine light weight with great mechanical strength, as much of the lantern as possible should be made of aluminium alloys.

Practical considerations of access, construction and appearance suggested that the best form for the lantern would be one in which the front glass and part of the reflector were carried on a hinged door. In the first lanterns the actual cast aluminium housing was made to the required contour, and buffed internally to form a reflecting surface ; but in later models silvered glass mirrors were substituted, which have a higher reflection factor and greater permanence.

Fig. 7 shows the lantern in its production form. It will be seen that the body of the lantern is a large aluminium alloy casting which houses the reflector and is bolted to a top casting which carries the lampholder and terminals and clamps directly on to the bracket arm. This form of mounting provides adjustment, both in elevation and azimuth, which allows the lantern to be pointed in any direction and then locked into position. It also simplifies erection, since the wiring can be carried out with the body of the lantern removed. The lampholder is flexibly mounted and the lamp bulb is held in the correct position in the reflector by means of a spring locating device. Either 80W. or 125 W. H.P.M.V. lamps can be used in the same lantern.

The hinged front of the lantern is glazed with fluted diffusing glass and carries a reflector made of anodised aluminium in the shape of a peak which forms part of the main optical system. A gasket is used to seal the front to the main body of the lantern, and toggle catches ensure that the gasket is uniformly compressed when the door is closed.

In order to render the whole lantern resistant to corrosion, all the metal fittings are made of materials which will minimise electrolytic action. Despite its large size, the total weight of the complete lantern, including reflector and lamp, is only about 20 lbs. ; the top casting, which is first attached to the bracket, weighs only 2 lbs.

THE ORTHOPTIC SIGHTING DEVICE.

With ordinary lanterns sending light in two main directions it is difficult to provide any means of adjusting the direction of the maximum intensity to suit varying road conditions. Any attempt to do this involves moving the lamp relative to the optical system, and usually there is no positive indication that the correct adjustment has been made. With the unidirectional lantern, however, as light is emitted in one direction only, the lamp setting in the reflector can be fixed and the whole lantern can be aimed in the required direction. To facilitate this the sighting device, shown in fig. 8, has been designed, and is arranged to show in degrees the depression and angle in azimuth of the main beam. The combination of the two which will best suit local conditions having been found, the orthoptic

Fig. 8.—Orthoptic sighting device.

sight is set and then fixed by means of a wingnut to each lantern in turn. The lantern is then aimed in such a direction that the next lantern on the same side of the road can be seen in the centre of the sighting tube. The lantern can be locked in this position and its adjustment will be correct and incapable of accidental variation.

PHOTOMETRIC PERFORMANCE OF UNIWAY LANTERN.

In a vertical plane through the direction of maximum intensity, the light distribution from the Uniway lantern is very similar to that from one side of a good street-lighting lantern of normal design, and it is only in other directions that the shape of the distribution is unusual. In fig. 9 the isocandle diagram of the Uniway lantern is compared with that of one side of the Horizal lantern, a representative unit of normal type using horizontal 400W. H.P.M.V. lamps. Only light emerging in directions within the shaded area reaches the street surface when the fitting is mounted 25ft. above the kerb of a 30ft. carriageway. It can be seen that a much greater proportion of the total light falls on the road in the case of the Uniway lantern. Table I gives figures showing the amount of light which actually reaches the road, compared with that from the Horizal lantern, and the Difractor lantern which employs a vertical 400W. H.P.M.V. lamp in a bowl refractor.

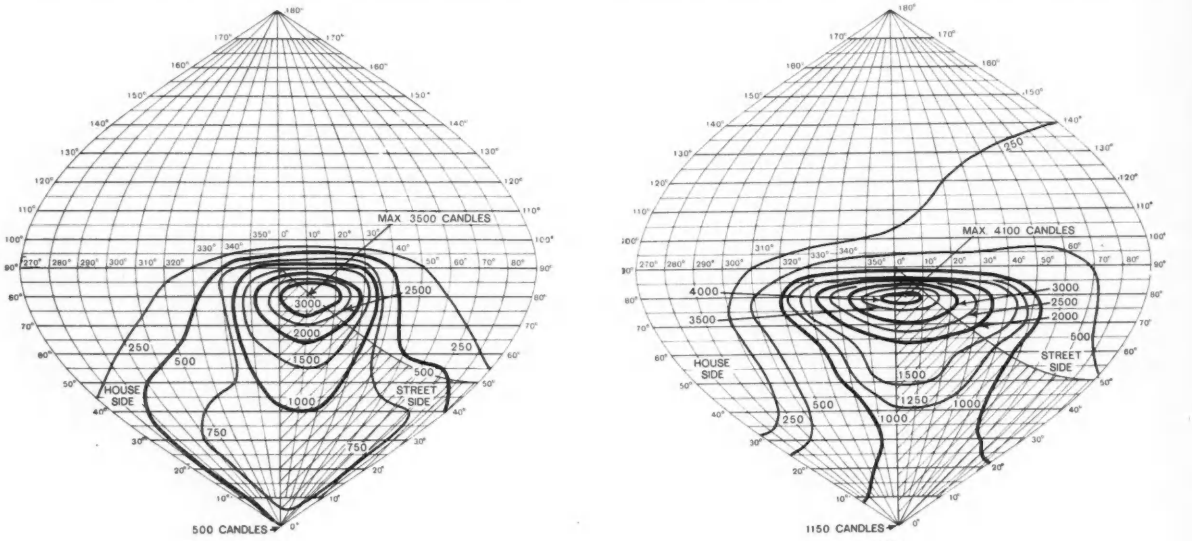


Fig. 9.—Isocandle diagrams for (a) Uniway lantern with 125W. H.P.M.V. lamp (4,000 lumens); (b) Horizal lantern with 400W. H.P.M.V. lamp (14,800 lumens).

TABLE I.

Lantern	Percentage of total light falling on road.
Difractor	25%
Horizal	30%
Uniway	37%

It must be remembered that only half the light given by the Horizal and Difractor lanterns is effective for any one observer, so that if these lanterns are used on one-way roads these figures should be halved. The whole of the output of the Uniway lantern, however, is given in the useful direction.

The Uniway lantern is also suitable for use with 80W. normal and fluorescent H.P.M.V. lamps. With the normal 80W. lamp the shape of the light distribution remains the same, but all intensities are reduced in the ratio of the light output of the two lamps, that is by 40 per cent. With either the 80W. or 125W. lamp the maximum intensity may be increased or decreased to suit special conditions by changing the front glass. When the 80W. fluorescent lamp is used a clear front glass is desirable, since the large diffuse light source of this lamp gives sufficient diffusion by itself, and no additional spread as given by a fluted glass is necessary. The intensities with this lamp, however, are such that a closer spacing is advisable.

STREET TEST OF UNIWAY LANTERNS WITH 125W. H.P.M.V. LAMPS.

Eighteen Uniway lanterns, nine on each carriageway, were erected on the Great Chertsey Road. In spite of the excessive average spacing of 190ft., good results were obtained when the lanterns were properly aligned. The appearance of the street, as seen in fig. 2, shows that nothing has been lost in restricting the amount of light falling beyond the boundaries of the roadway, while calculations from illumination values and brightness distribution confirm that the expected high revealing power is obtained. Experience in an actual highway with traffic disposed of certain difficulties which earlier experiments had foreshadowed, such as the performance in wet weather, the effect upon drivers entering a unidirectional system from a side road, pedestrian

conditions and other practical problems. All these potential difficulties were found to be of small practical importance.

Both 80W. and 125W. lamps were tried in this installation and in spite of the fact that the road surface is rather matt, all observers agreed that even with the lower wattage the results were very satisfactory. These results become impressive when it is realised that with 125W. lamps the light output per foot of carriageway is about one fifth, and with 80W. lamps about one eighth of the amount normally employed on such carriageways for a similar result.

CONCLUSIONS.

It would appear that the unidirectional system of lighting, using Uniway lanterns with low wattage H.P.M.V. lamps, goes a long way towards solving the outstanding problems of the lighting of one-way and double-carriageway roads. The drastic reduction of wattage made possible by the system, and the consequent economy in running costs, substations and cables makes the lighting of long stretches of double-carriageway road in the open country an economic possibility. The saving may amount to several hundred pounds per annum per mile of road. In addition, driving comfort and revealing power are improved, and the lantern itself is simple to maintain.

The problem of lighting double-carriageway roads is now becoming very much more acute as the Ministry of Transport has indicated that 3,800 miles of trunk road will be reconstructed with double carriageways. With existing methods the cost of lighting even a small part of this mileage may be prohibitive. By the use of unidirectional lighting, however, it is possible to light both carriageways at a cost which is little greater than that of lighting a single-carriageway road with ordinary lanterns.

REFERENCES.

1. Waldram, J. M., Illum. Eng. XXVII, p.305, Oct., 1934.
2. Beggs, S. S. and Wilson, G. H., G.E.C. Journal VI, No. 3, Aug., 1935.
3. Final Report of the Ministry of Transport on Street Lighting, Aug., 1937.
4. Waldram, J. M., Trans. I.E.S. (Lond.), Dec., 1938.
5. Smith, F. C., Trans. I.E.S. (Lond.), Dec., 1938.

"Osira" Lamp Lighting at Morris Motors, Ltd., Cowley.

The chassis assembly section in the Cowley Works of Morris Motors, Ltd., illuminated by 125 watt "Osira" extra high pressure mercury vapour discharge lamps, mounted in dispersive reflectors. The average service illumination obtained is 9 to 10 foot-candles.

The Design of Fractional Horse-Power Induction Motors.

PART I.

By N. F. T. SAUNDERS, B.Sc.
General Manager, Coldair Ltd.

There is available to the designer of induction motors a considerable amount of published work, which enables designs to be established conveniently and with a high degree of accuracy. This statement, however, does not apply to motors of fractional horse-power output, especially for single-phase working.

In this article, using analytical methods, the author establishes simple formulae for the performance data required in connection with single-phase motors. Correction factors, applicable to the simple formulae commonly used in the design of polyphase motors, are also given. These correction factors are based on the conditions generally existing in fractional horse-power motors, which differ considerably from those found in large machines.

The article also includes recommendations regarding the active material required and its proportions, and a method for determining slot ratios which are relatively free from cogging and noise.

Stator windings having a sinusoidal space distribution, and the calculation of stator end-winding length and projection, are also dealt with.

This article was read as a paper before The Institution of Electrical Engineers in January, 1939.

(1) INTRODUCTION.

FROM the evidence of published work on the subject the methods employed in the design of induction motors appear to have been evolved from the study of large machines. When those methods are applied to the design of fractional horse-power (f.h.p.) motors, the results obtained are not very satisfactory. Graphical methods, except possibly for very large machines, are not now popular. The majority of designers probably use a mathematical process based on the method of inversion. For practical use, the formulae are simplified by making assumptions, as by neglecting certain small quantities, or by taking as constant certain quantities which, in fact, vary slightly. A considerable degree of accuracy is attained by using these simplified formulae in conjunction with correction factors, as described by Hoseason.[1] Similar mathematical methods are quite suitable for f.h.p. machine design, provided the simplified formulae and correction factors used are based on appropriate assumptions.

It happens, also, that because in large sizes single-phase induction motors are comparatively rare, there is very little published work on the practical design of this type. To the designer of f.h.p. machines this is a serious matter, since in this range single-phase motors are of great importance.

It is interesting to note that the single-phase induction motor appears to have an extraordinary fascination for the theorist. Very many papers have been published on the theory of this machine, many of them exhibiting mathematical ingenuity of a high order, but it is doubtful whether any of them contribute anything either additional to, or in elucidation of, the original works of Steinmetz.

The object of this paper is to discuss in detail the practical design of f.h.p. motors, with special reference to the single-phase type. Simplified formulae are given, together with correction factors appropriate to this class of machine. For the sake of brevity, familiar calculations, such as that required to establish the ampere-turns, are omitted. Finally, design sheets are given, which are arranged specially to suit f.h.p. motors.

(2) GENERAL CONSIDERATIONS.

The principal factors involved in the design of f.h.p. induction motors are the following :—

(*a*) For standard and general requirements it is usual to design the machine as a single-phase motor, and then to adapt it to polyphase circuits. Nevertheless, as will be seen, the fact that it will be required to serve as a polyphase motor has to be borne in mind throughout the process of design.

(*b*) In single-phase motors for general requirements, starting torque and overload capacity are of primary importance and efficiency and power factor are generally regarded as of secondary importance. The limitation is usually temperature-rise, which in turn, is governed by size.

(*c*) The majority of machines are required to operate at 1,500 r.p.m. synchronous speed (*i.e.* 4 poles, 50 cycles per sec.). It is therefore usual to proportion standard designs to give

1 *Journal I.E.E.*, 1925, vol. 63, p. 280.

round ratings (*i.e.* $\frac{1}{8}$, $\frac{1}{6}$, $\frac{1}{4}$, $\frac{1}{2}$, $\frac{3}{4}$ h.p.) at this speed with the maximum economy in material, and then to use the same frames, with modified stampings—if necessary, or economically allowable—for the most suitable ratings at other speeds.

(*d*) The modern tendency is to demand silent running, and the steps necessary to eliminate noise of electrical origin represent one of the most important factors in design.

(*e*) The perfecting of enamel-covered wire has had an important influence on the design of small motors. Such wire is now used almost exclusively for f.h.p. stators.

(*f*) Proportions are influenced by standardization requirements, and by such practical considerations as the minimum bore through which an operator can conveniently pass the hand when winding.

(*g*) Several different starting methods for single-phase motors are in use. The most recent to become popular is the capacitor-start, the development of which is due to the advance in the technique of electrolytic condensers.

(*h*) The above factors refer to machines for what may be described as standard requirements. In addition, there are many instances where the motor is designed for a particular purpose and may, in consequence, be quite unsuitable for any other application. An example of this is the high-speed machine-tool motor operating from a high-frequency supply.

The increasing diversity in the application for which small motors are required, and the severity of the operating conditions, together with the invariable demand for low manufacturing cost, necessitate accurate design methods which may be used with confidence in place of the trial-and-error procedure so prevalent in the past.

(3) ACTIVE DIMENSIONS.

The D^2L value, in inch units, required for a given horse-power in the case of a pure split-phase motor (*i.e.* with no condenser) for 4 poles, 50 cycles per sec., and any voltage up to 250 volts, may be taken as :—

$$D^2L \text{ (cubic inches)} = 25 + (162 \times \text{horse-power}) \quad (1)$$

where D and L refer to the outside dimensions of the stator laminations.

It is quite usual to employ the same laminations for 4 and 6 poles, and in some cases also for 8 poles. For 2 poles the gap diameter may be reduced, subject to the fact that about $2\frac{3}{8}$in. is the minimum convenient bore for winding. For 8 or more poles the gap diameter is usually increased, but, if so, the diameter chosen may be a compromise between the ideal dimension for 8 and 10, or 8, 10, and 12 poles, depending on the demand which is anticipated for these numbers of poles.

Fig. 1 gives recommended ratios of gap diameter to outside diameter for various numbers of stator

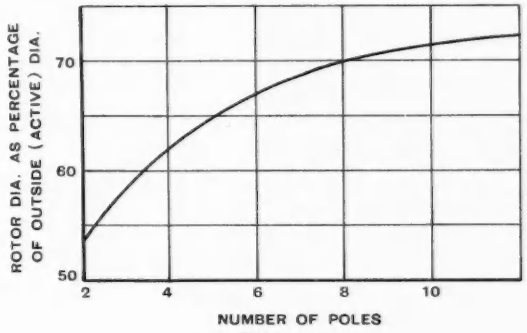


Fig. 1.

poles. It is recommended that in 4-pole designs the radial air-gap should be about 0·35 per cent of the rotor diameter. In 2-pole machines it should be 0·50 per cent ; it may be decreased to 0·25 per cent for 8 poles and so on. For instance, a single-phase ceiling fan motor having 28 poles might have an air-gap of only 0·13 per cent of the rotor diameter. As a general rule it may be taken that the radial air-gap should be

$$\text{Gap} = 0{\cdot}007 \times (\text{Rotor diam.}) \times \sqrt{\left(\frac{1}{2p}\right)} \quad . \quad (2)$$

where p is the number of pole pairs for which the stator is wound.

The outside diameter of the motor and the height of centres are usually fixed by commercial considerations. The outside diameter of the stator laminations will then depend on the thickness of the shell (if any) and whether an air space is to be provided between them and the shell, for ventilation purposes.

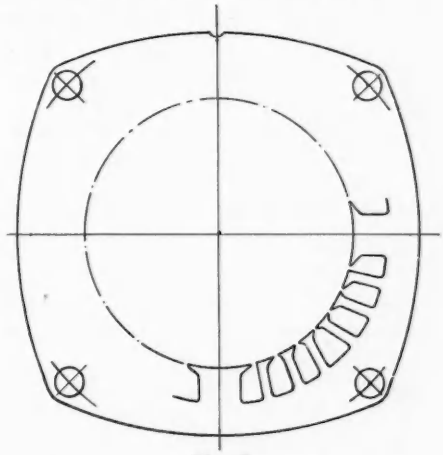


Fig. 2.

The latest practice is to use a rolled-steel shell or die-cast shell of comparatively thin section and to provide either an annular space around the core, or vent holes through it. The objections to vent holes are that they must necessarily be of small diameter, and a number of small holes present a greater

resistance to the passage of air than the equivalent cross-section in an annular passage; and that they easily become clogged if the motor is not working in a clean atmosphere.

If a machine is required only as a single-phase motor, it is advantageous to use slots of uneven sizes (fig. 2) and, if useful, the outside of the laminations may depart from the circular form. This, however, is usually only done in the case of repulsion-start motors. The stator laminations of squirrel-cage motors are generally made symmetrical so that they may be wound for polyphase operation.

(4) STATOR SLOTS.

It is recommended that the bottom of stator slots should be semi-circular (fig. 3). This reduces the cost of tool-making and gives a definite improvement in the flow of flux into the tooth. A square end is bad from these points of view, while it is found that the extra space provided in the corners cannot effectively be utilized. Also, a slot cell which is shaped to fit in a square-ended slot is liable to split along the sharp bend, and the spaces which are left in the corners are bad from the heat-transmission aspect.

The top of the slot, however, should be formed by sloping projections on the teeth (fig. 3). It is found that the slot cell holds better during winding, and the closing of the slot after winding is easier

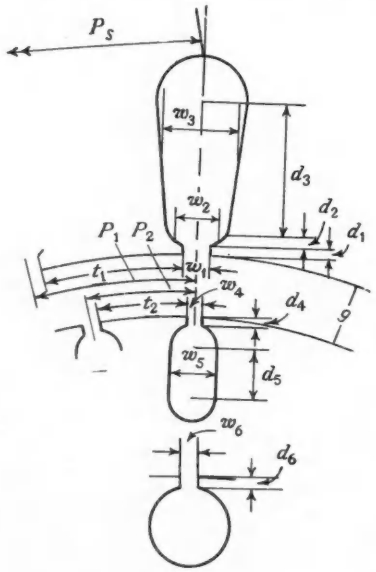


Fig. 3.

$t = \frac{t_1 + t_2}{2}$

with this shape than with a semi-circular shape. An angle of 27° gives good proportions, and is convenient in calculation, since tan 27° is approximately 0·5, so that the dimension d_2 (fig. 3) is quickly arrived at from the dimension w_2.

The teeth should be made not quite parallel. It is easily seen that there is no case for parallel-sided slots in the class of machines under discussion, as bar windings are out of the question. Since, however, a small proportion of the flux is lost in its passage through the teeth, it is reasonable to make them depart from the parallel by this amount.

It is recommended that on very small machines the tooth width should decrease by about $7\frac{1}{2}$ per cent while for larger machines it should decrease by about 5 per cent. In general, this factor should be used to round off calculated slot dimensions rather than regarded as a rigid requirement. The slot opening should not be made less than about 0·075in. unless absolutely necessary, since winding difficulties arise if it is smaller than this. Subject to this limitation, the opening should be about 20 per cent to 25 per cent of the slot pitch.

The thickness of the tip at the opening (fig. 3, d_1) should be about 0·04in. to 0·06in. If the bore is to be ground, or otherwise finished to size, allowance must, of course, be made on this dimension accordingly. It is generally found that internal machining of the stator bore is not necessary if the construction is good, and should be avoided since the short circuiting of laminations, which is liable to occur, more than offsets any gain from the finish.

A popular thickness for laminations is 0·018in., and unless very high efficiency is aimed at, this is quite thin enough. It is a good plan to place two laminations $\frac{1}{16}$in. thick at either end of the core to help to keep it tight along the teeth. These thick laminations may, with advantage, be dished before being placed in position. The grade of iron used for stator laminations should be chosen for its high permeability rather than its low iron loss. Any gain in iron loss due to the employment of low-loss iron is usually more than offset by an increase in the copper loss due to the magnetizing current.

Considerable advantage is to be gained by annealing laminations after stamping. During the stamping process the iron appears to become work-hardened around the slots, and this hardening affects the permeability of the iron. This is obviously particularly marked in a case where the teeth are very narrow, or where the flux density is high. Annealing also seems to help in reducing "noise," probably because the core packs tighter.

The use of rivets to hold the laminations together is sometimes condemned, but the author is of the opinion that losses due to steel rivets placed near the outer periphery are negligible. What is more important is that these rivets should be adequate to hold the laminations in a really tight pack. The section of the rivets should not be less than that required to sustain the pressure which is necessary to compress the pack during manufacture.

(5) COPPER ROTOR WINDINGS.

In dealing with small rotors, particularly if a large number of bars is employed (*i.e.* between 30 and 50), it will be found that round bars are undesirable, owing to the narrow "tooth" which results. A rectangular bar with rounded ends (fig. 3) is recommended. The depth of the bar should be kept a minimum. A good ratio of depth to width is usually between $2\frac{1}{2}$ and 3 to 1. The actual proportions should be chosen so that the real flux density in the teeth at points situated two-thirds of the distance from the wide end is about equal to that in the stator teeth.

The shape of the slot should be similar to that of the bar. The clearance allowed round the bar is very important. It is now common practice to make the copper bars serve as rivets to hold the laminations tight, and if the bars are not a correct fit in the slot, great difficulty is experienced in manufacture, especially if the slots are skewed. A clearance which has been found satisfactory in the case where the skew is equal to twice the slot pitch is $12\frac{1}{2}$ per cent on the width of the bar and 10 per cent on the depth. It must be appreciated that this clearance depends very largely on the actual method used for riveting the bars up, and these clearances cannot, therefore, be regarded as definite.

It is quite a common practice to employ no slot opening on the rotor. In the author's opinion, the advantages of this practice are questionable, while the disadvantages are definite and important. First the "zigzag" leakage is increased to an extent practically impossible to estimate. The iron loss due to the tooth pulsations is similarly increased. The most serious objection, however, is the fact that a constant value for the rotor slot leakage cannot be relied on. A slight difference in the position of the slot in successive batches of stampings, or a variation in the amount of metal removed from the rotor periphery to obtain the air-gap, produces marked differences in test results. A common source of trouble is due to eccentricity as between the blank and the piercing of the slots, so that on one side of the rotor the bridges are thicker than on the other. This last point is liable to accentuate magnetic noise. It is recommended, therefore, that an opening of 0·025 to 0·035in. with a lip thickness of 0·015 to 0·025in. be employed. These dimensions are, or course, finished sizes.

For end rings a common and convenient practice is to use copper discs punched out like the steel stampings. A suitable thickness is about 0·063in. If a greater thickness is required more than one disc should be employed. Thicker discs are more difficult to punch, and cause trouble in the assembly of skewed slots. Satisfactory contact is achieved if the bars and rings are tinned before riveting and dipped in solder afterwards.

(6) ALUMINIUM ROTOR WINDINGS.

The ratios of gap diameter to outside diameter given in fig. 1 apply to rotors having copper windings. Of recent years the use of cast aluminium for squirrel-cage rotors has been extended to f.h.p. machines. While, in a case where plant has been installed to cast large rotors, it may be economical also to cast small ones, the installation of plant purely for the latter is a matter for very careful investigation.

The specific resistance of pure aluminium is given as 1·68 times that of copper. Although it is quite possible to regulate the "impurities" in the metal used for casting, and so to maintain the specific resistance within reasonable limits, the actual figure is invariably higher than that for pure aluminium. Depending on the casting method and the proportions of the squirrel cage, other constituents, such as silica, may be deliberately added to improve the flow of the metal, and thus obtain homogeneous and consistent results. Any such additions, of course, increase the specific resistance. Great care must be taken to control the casting process once production has commenced, otherwise serious troubles, often difficult to diagnose and remedy, are experienced.

The possibility of extensive standardization is also an important factor. In a plant where large numbers of similar machines are manufactured, and the construction of odd machines for special applications is avoided, the case for the cast rotor is much stronger than in a plant which undertakes the production of a large variety of types.

Unless all the practical problems involved are fully considered, and the cost of surmounting them accurately estimated, quite unjustifiable conclusions may be drawn regarding the saving to be achieved by the use of cast rotors in small motors. The question of cast-aluminium rotors versus copper rotors is, therefore, essentially one of manufacturing interest. From the technical aspect the advantage is almost entirely with the copper rotor.

Since the slots for cast bars must be larger, they must either be deeper than the slots for the equivalent copper bars, or the rotor diameter must be increased. To a certain extent this difficulty may be modified by the use of pear-shaped slots giving parallel teeth. If the slots are made very deep the "harmonics" in the speed/torque curve are accentuated, but to some extent this may be offset by the greater ease with which the slots may be skewed. Increasing the rotor diameter necessitates either increasing the outside dimensions, which is undesirable for many reasons, or working at higher flux densities and with tighter and more complicated stator windings. Higher densities have an adverse effect on overload-capacity and other performance figures, while tighter windings may involve not only increased winding cost but increased cost of copper.

A point not to be lost sight of is that if the amount

of copper in the coils is increased, it is usually necessary also to increase the length of mean turn, so that the amount of copper in the end winding increases more than in the same proportion as the copper in the slot. Finally, copper rotors can be made without difficulty to show extreme consistency in test results, and while it is not disputed that consistent results can also be obtained with cast-aluminium rotors, not only are the practical difficulties greater but data obtained on one design are less applicable to another.

(7) SLOT NUMBERS.

It is well known to designers of electrical machines that the numbers of slots on the stationary and revolving elements are important, but that the ratio between the two is even more important. From the point of view of performance and quiet running, it is better to use a large number of slots, but of course there are practical limits to this. For example, a motor having a gap diameter of 3½in. might have, for 4 poles, 24, 36, or 48 slots. Intermediate numbers may be used, but, if this is done, the winding becomes less simple. It will be found that 36 slots is about the practical limit for such a size, because if more are used the minimum practical thickness of slot insulation becomes too large a proportion of the slot width, and the cost of winding (being to a large extent a function of the number of coils) becomes prohibitive. For such a size, however, 24 slots is quite common, and although with simple windings 36 slots gives a quieter machine, much of this disadvantage may be overcome if the winding in 24 slots is distributed as described later in the article. Since the stator winding generally represents the greatest single item of cost in the machine, a careful consideration of the various alternatives is well repaid.

With regard to the number of rotor slots, here again the rule should be to employ as many as practical and economic considerations will allow. The limit for design reasons may be taken as when the depth of the bar exceeds 4 times the width, although for other reasons this limit may be too high.

(8) SLOT RATIOS.

On the subject of slot ratios in induction motors, much has been said and written. It was held for a long time that the number of rotor slots should be a prime number, or that the number must be odd. In actual practice, it is found that neither of these conditions is necessary. A slot which gives a quiet machine, both during starting and while running, will also be found to give a good speed/torque characteristic. Skewing, is, however, advisable, even with a good slot ratio. It may also be taken that a ratio which gives good results on single-phase will also give good results on 3-phase, but the reverse is not always true. It is advisable, therefore, to choose a ratio which gives satisfaction when the machine is wound for single-phase operation.

The author has found that the following method, which is largely empirical, gives reliable results. The fundamental and "harmonic" stator poles should first be written down, thus: $2p$, $3\times2p$, $5\times2p$, $7\times2p$, $9\times2p$, etc. The slot ratio is a good one if the two numbers N_1, N_2, given by the following formula, are equal to two of the above numbers, excluding the first. Thus

$$N_1 \text{ or } N_2 = 2(p \pm \delta). \quad . \quad . \quad . \quad (3)$$

where δ is the difference between the number of slots on the stator and the number on the rotor.

It is immaterial whether N_1 and N_2 are positive or negative, and whether the stator or the rotor has the larger number of slots. Further, it may be taken that the larger the numbers given by this formula, the more satisfactory is the slot ratio. It will be noted that this gives a series of possible ratios for one number of stator poles. It has been already stated that it is usual on f.h.p. motors to use the same number of laminations for more than one number of poles. This applies also to rotor laminations. It is therefore necessary to examine any proposed ratio for all numbers of poles for which it will be used. Where a compromise is necessary, it may be taken that the nearer the numbers N_1 and N_2 are to two of the "harmonics" the better, but that it is more necessary to achieve coincidence when the number of stator poles is small than when it is large.

For example, considering a stator with 36 slots, to be wound for 4 poles, the fundamental and "harmonic" stator poles are

4, 12, 20, 28, 36, etc.

Choosing 44 rotor slots,

$$N_1 \text{ and } N_2 = 2(2 \pm 8) = -12 \text{ or } 20 \quad . \quad (4)$$

Choosing 48 rotor slots,

$$N_1 \text{ and } N_2 = 2(2 \pm 12) = -20 \text{ or } 28 \quad . \quad . \quad (5)$$

Either of the above rotors will therefore be satisfactory. If now the machine is to be wound for 6 poles, the fundamental and "harmonic" stator poles are

6, 18, 30, 42, 54, etc.

and 44 rotor slots gives

$$N_1 \text{ and } N_2 = 2(3 \pm 8) = -10 \text{ or } 22 \quad . \quad (6)$$

but 48 rotor slots gives

$$N_1 \text{ and } N_2 = 2(3 \pm 12) = -18 \text{ or } 30 \quad . \quad (7)$$

It is therefore better to use 48 slots, so that the machine will be equally suitable for winding for either 4 or 6 poles.

(9) STATOR WINDINGS.

For single-phase machines the concentric type of winding is generally used. For 3-phase machines a lap winding, either single or double, is common, but a winding which may be described as "concentric-

lap" is useful, since it gives a rather smaller end-winding length than a lap winding. In this winding the coils for one phase and one pole are formed in a concentric group, but one side only of each coil is placed in its slot, and the first sides of the next group are placed in their slots before the second sides of the first group. This winding keeps down the end winding projection, but occupies rather more space in the radial direction as compared with a lap winding. In the case of a 2-pole stator a lap winding is preferable, since chording can be used to advantage.

A valuable contribution to silent running in single-phase motors is the distribution of the stator winding in order to approximate to a sinusoidal flux space distribution. In a simple single-phase concentric winding, the main winding usually occupies two-thirds of the slots, and the starting winding the remaining one-third, and all coils of the same winding have the same number of turns. To approximate to a sinusoidal distribution, the main winding must be spread over 80 per cent to 85 per cent of the total number of slots, the coils do not all have the same number of turns, and certain slots are shared by the two windings. For a given number of stator slots, this type of winding is more expensive in labour than the simple type. The effect on silent running, however, is important, and, for a given degree of silence, such a winding allows a smaller number of stator slots to be used, so that in this way the winding cost may be brought back to normal.

By way of example, it is found that a 24-slot 4-pole stator with a distributed winding will probably give as quiet a machine as a 36-slot stator with a simple winding. A good practice, therefore, is to employ 36 slots with a simple winding for ordinary use, and a distributed winding in the same stator to give a "super-silent" machine. Since some of the slots are shared by both windings, care must be taken to see that the two windings together with the insulation required between them are not too much for the size of the slot.

TABLE 1.

Coil	Tooth angle (θ) (degrees)	Sin θ	Difference	Conductors
5	7.5	0.13	0.13	14.1
4	22.5	0.383	0.253	27.5
3	37.5	0.61	0.227	24.7
2	52.5	0.79	0.18	19.6
1	67.5	0.92	0.13	14.1
				100%

(10) SINUSOIDAL DISTRIBUTION.

Referring to fig. 4, it will be seen that in order to approximate to a sinusoidal distribution the number of conductors in each slot should be chosen so that they build up the flux in the adjacent tooth to the point on a sine wave which intersects the vertical line through the tooth centre. That is to say, the

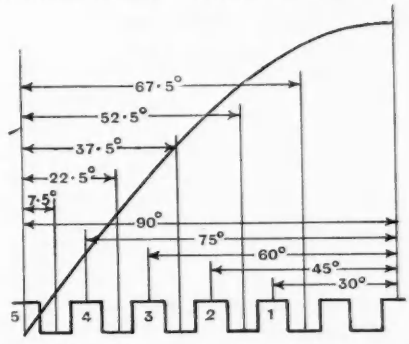


Fig. 4.—Winding diagram for one pole of single-phase 4-pole motor having 48 stator slots.

number of conductors in the slot should be based on the angular position of the adjacent tooth and not on the angular position of the slot itself. The outer coil should make a full pole pitch and thus occupy the same slots as the outer coils of the poles on either side of it. The required number of turns may be established by the following method, which is best explained by reference to an example.

Fig. 4 shows diagrammatically the winding for one group (*i.e.* one pole) of a single-phase 4-pole motor, having 48 stator slots. This amounts to 12 slots per pole, of which 9 are occupied to some extent by the running winding. The angular displacement of each tooth towards the centre of the pole is marked, and entered in col. 2 of Table 1. The corresponding sine is entered in col. 3, and in col. 4 are entered successive differences. The total number of conductors having been established (see later), it is entered in the space at the bottom of col. 5, and the numbers of conductors in each coil are then calculated by proportion to the corresponding difference in col. 4.

(11) DISTRIBUTION FACTOR AND CHORD FACTOR.

Unless the winding is concentrated in a single coil per pole, a distribution factor for use in calculating the flux must be established to allow for the distribution of the conductors over the pole face. Referring again to fig. 4, it will be seen that each coil is effective in creating flux through the pole according to the proportion of the pole which it embraces. That

TABLE 2.

Coil	θ_d (degrees)	Sin θ	Conductors	Effective conductors
1	30	0.5	14.1	7.05
2	45	0.707	27.5	19.45
3	60	0.866	24.7	21.4
4	75	0.966	19.6	18.95
5	90	1.000	14.1	14.1
			100%	80.95

is, it is effective in proportion to the angular displacement (from the centre of the pole) of the slot in which it lies. In the case which is taken to illustrate sinusoidal distribution it is possible to calculate the distribution factor as shown in Table 2.

The distribution factor in this case is therefore $K_d = 0{\cdot}81$. This factor has been established for a number of typical cases and is given in Table 3.

The problem of the squirrel-cage motor is a special case of the above. When the machine is wound as a single-phase motor all the conductors are

TABLE 3.

Single-phase Concentric Windings.

Stator slots	Stator poles	Phase	Slots per phase	Coil pitch	Turns per coil	K_d
24	4	Run	16	1–6 2–5	1 1	0.836
		Start	8	4–9	1	0.966
24	4	Run	18	1–7 2–6 3–5	1 2 1	0.808
		Start	6	4–10 5–9	1 1	0.933
36	4	Run	24	1–9 2–8 3–7	1 1 1	0.831
		Start	12	5–14 6–13	1 1	0.97
36	4	Run	24	1–10 2–9 3–8 4–7	1 2 2 1	0.819
		Start	12	6–14 7–13	1 1	0.925
48	4	Run	32	1–12 2–11 3–10 4–9	1 1 1 1	0.829
		Start	16	7–18 8–17	1 1	0.957
48	4	Run	32	1–13 2–12 3–11 4–10 5–9	1 2 2 2 1	0.822
		Start	16	7–19 8–18 9–17	1 1 1	0.944

active with respect to the running winding. It is then a case of conductors spread over the whole pole-face. A calculation by the above method shows that for the usual number of rotor bars the distribution factor may be taken as 0·64. When the stator is wound for 3-phase operation the rotor represents the case of a winding distributed over one-third of the pole face, and the distribution factor is then 0·96. In the case of a lap winding a chording factor must be employed. If the pole pitch is a slots and the actual pitch is b slots then the chording angle is given by

$$\theta_c = \left(\frac{a-b}{a}\right) \times 180^\circ \quad . \quad . \quad . \quad . \quad (8)$$

The chording factor is given by

$$K_c = \cos\left(90^\circ \times \frac{a-b}{a}\right) \quad . \quad . \quad . \quad (9)$$

(12) WINDING FACTOR.

Now that the use of enamelled wire is so common, accurate calculation of the number of conductors which can be wound in a slot is of even greater importance than before. The secret of successful mass production of stators wound with this wire lies in the specification of the correct number of conductors per slot. The troubles likely to be experienced if the winding is too tight are easily imagined, but what is often overlooked is that a winding which is too slack will also give trouble due to the movement of the wires after winding. When the slots are shaped as recommended in fig. 3 and the slot opening is closed by an inverted trough of leatheroid, it will be found that a satisfactory winding factor is 70 per cent.

The winding factor is employed as follows: The net area of the slot is found by taking the dimensions of the slot, less the thickness of the slot insulation. In this connection it should be noted that when the slot insulation is built up of two or more separate thicknesses of material, the resultant thickness must be taken as the sum of the constituent thicknesses plus 15 per cent for each additional thickness over one. For instance, using 0·01in. leatheroid and 0·007in. empire cloth, the total thickness should be taken as 0·0195in. The winding in the slot is proportional to $d^2 z_1$, where d is the diameter over the wire insulation and z_1 is the number of conductors per slot. The number of conductors which can be put in the slot is then given by

$$d^2 z_1 = (\text{Net area of slot}) \times 0{\cdot}70 \quad . \quad (10)$$

(13) END-WINDING LENGTH AND PROJECTION.

A reliable method of calculating the length of mean conductor, which of course, means a reliable method of calculating the mean length of the end winding, is very useful. The well-known methods, whereby the lengths of formed coils are established, are inapplicable to small wire-wound stators. The following method yields, first, the projection P_e of the over hang (fig. 5), which is an extremely important figure now that there is a tendency to keep down dimensions to a minimum; and, secondly, the length of the end winding. From the latter follows the length of mean conductors by adding the core length.

It is useful to check existing designs in order to cut down waste. It is probable that in most winding

shops the development of formers is left to the foreman in charge, with the results that formers which are made too small are corrected, but those which are made too large are left alone unless complaints are received from the assembly department on account of excessive projection of the end winding.

In a concentric winding the projection is proportioned to the amount of copper in the slot and the number of coils per group. It also depends on the number of poles for which the stator is wound. The projection is given by the expression

$$2{\cdot}1\sqrt{[p \times (\text{coils per group}) \times d^2 z_1]} \quad . \quad (11)$$

It may be taken that windings can economically be made to conform to this formula except in the case where very heavy wire is used for low voltage. The figure given by this formula is exclusive of any tape or other insulation wound round the end winding, and of such items as connectors.

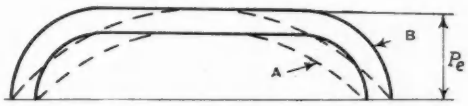


Fig. 5.

The shape of the end portion of a coil in a concentric winding is between an arc A (fig. 5) and the rectangular shape B. The true length l_e may therefore be taken as the length B multiplied by a constant c less than unity. Thus

$$l_e = c\left[\pi \times \frac{P_e}{2} + (P_s - P_e)\right] \quad . \quad . \quad (12)$$

where P_s is the pitch of the mean coil taken on the circle touching the bottom of the slots (fig. 3).

In practice, it is found that the total length of a coil has an influence on the ease of winding it into the slots. In the case of the two machines, identical except for the length of core, it is found that on the longer core-length the end winding may be shortened slightly without adding to the difficulty of winding.

The above expression (12) may therefore be modified by the factor

$$1 + 0{\cdot}07\,\frac{\text{Rotor diameter}}{\text{Core length}} \quad . \quad . \quad . \quad (13)$$

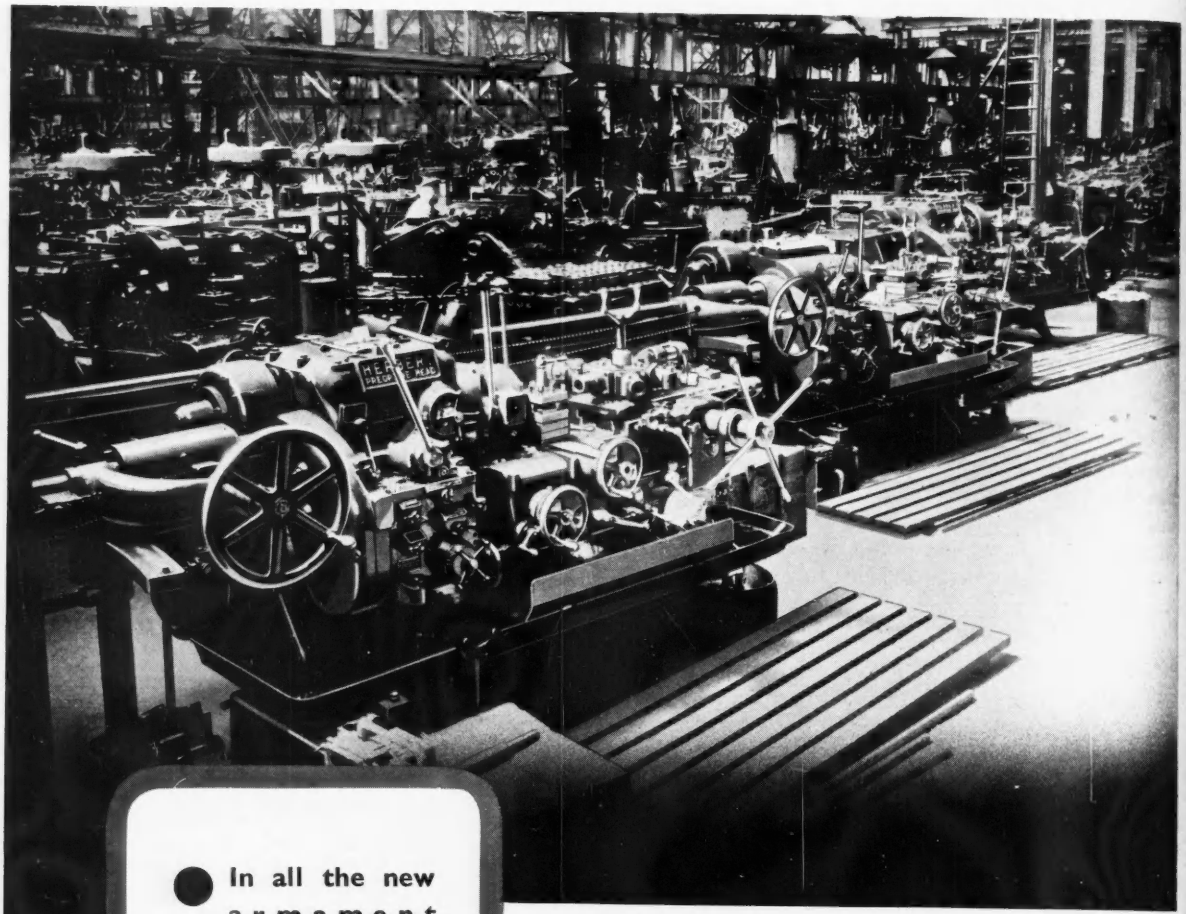
The end-winding length (single-phase) is then given by

$$l'_e = 0{\cdot}90\left[1 + 0{\cdot}7\frac{\text{Rotor diam.}}{\text{Core length}}\right]\left[\pi \times \frac{P_e}{2} + (P_s - P_e\right] \quad . \quad (14)$$

In the case of 3-phase stators employing the "concentric-lap" winding, the expression is

$$l'''_e = 0{\cdot}95\left[1 + 0{\cdot}07\frac{\text{Rotor diam.}}{\text{core length.}}\right]\left[\pi \times \frac{P_e}{2} + (P_s - P_e)\right] \quad . \quad (15)$$

[*To be continued*]



● In all the new armament factories, equipped with the world's best machine tools, Herbert capstan and turret lathes will be found engaged on difficult and exacting work demanding the utmost rigidity, accuracy and ease of operation.

HERBERT CAPSTAN & TURRET LATHES

ALFRED HERBERT LTD., COVENTRY.

reau of Standards

FEB 27 1939

G.E.C. Journal

IN THIS ISSUE

ELECTRICAL PROGRESS AND DEVELOPMENT DURING 1938

THE HIGH POWER HOT CATHODE MERCURY VAPOUR RECTIFIER

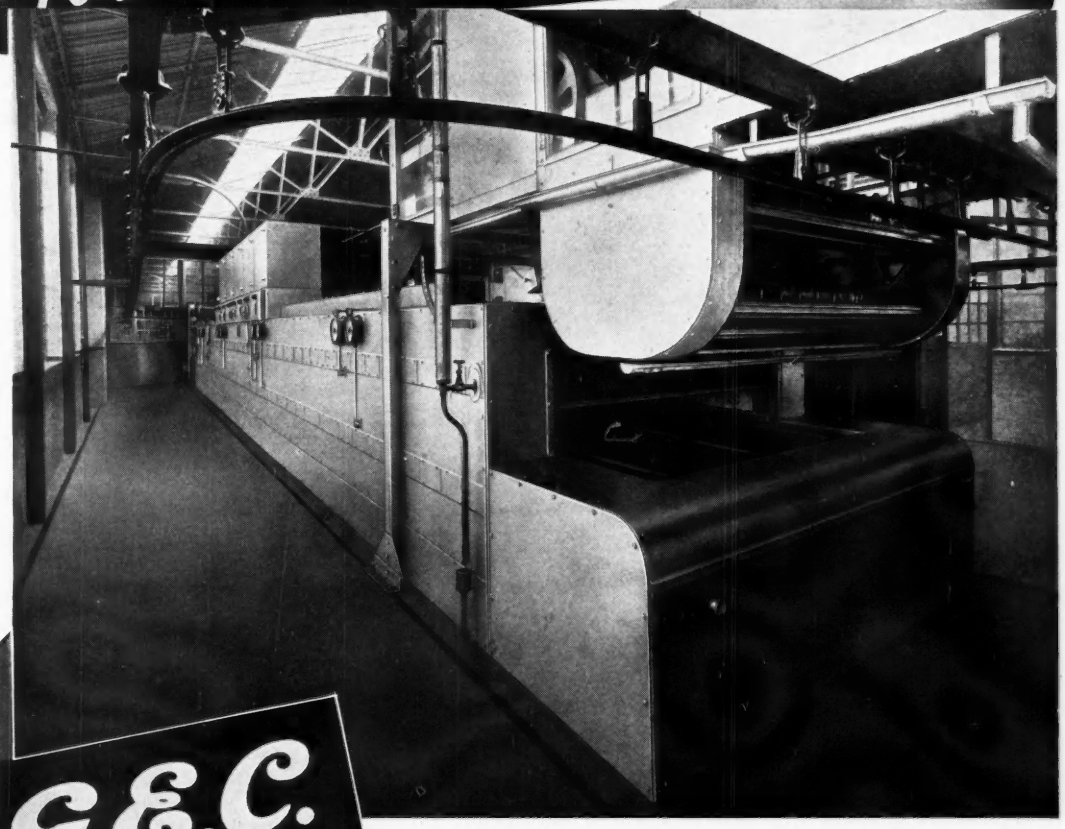
ROTOR VOLTAGE OF INDUCTION MOTORS DURING STARTING

ARC CONTROL PUTS

Vol. X., No. 1. February, 1939

THE GENERAL ELECTRIC CO·LTD
OF ENGLAND

The first all-electric travelling oven in England for bread baking



G.E.C. ELECTRIC BAKERY EQUIPMENT

An installation which typifies the steady development of G.E.C. equipment for the Baking industry during recent years.

This oven is 50ft. long and 5ft. 6ins. wide. It is part of an installation at Lees Bakeries Ltd., Newcastle-on-tyne, which includes a G.E.C. 35ft. travelling oven for confectionery.

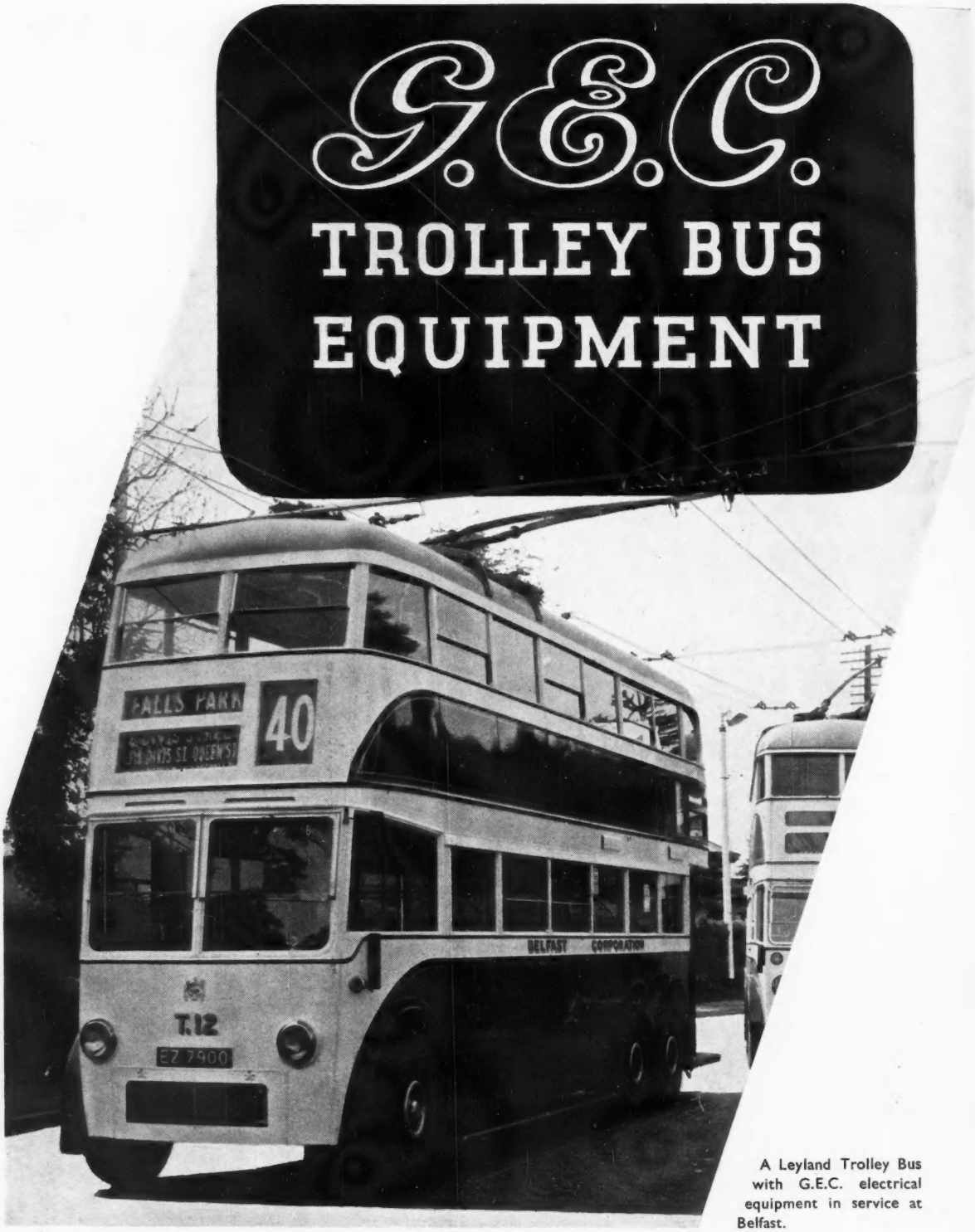
The ratings are 350 kW and 200 kW respectively, the loading being arranged in eight zones, with separate automatic temperature control gear on each zone.

John Lysaght Ltd., Constructional Works, Bristol

HANGING
BY A THREAD
In the air life literally hangs by a thread. That is why the majority of threads in the aircraft industry are cut with Coventry and Tangic Dieheads and Dies—threads to A.I.D. requirements at high rates of production.
These dieheads are the world's best thread-cutting tools, backed up by an efficient service before and after sales.
COVENTRY DIEHEADS.
Twelve sizes ¼" to 4½".
TANGIC DIEHEADS.
Four sizes ⅜" to 2"
Wide range of dieheads and dies for all standard threads usually in stock.
ALFRED HERBERT LTD.
COVENTRY

G.E.C.

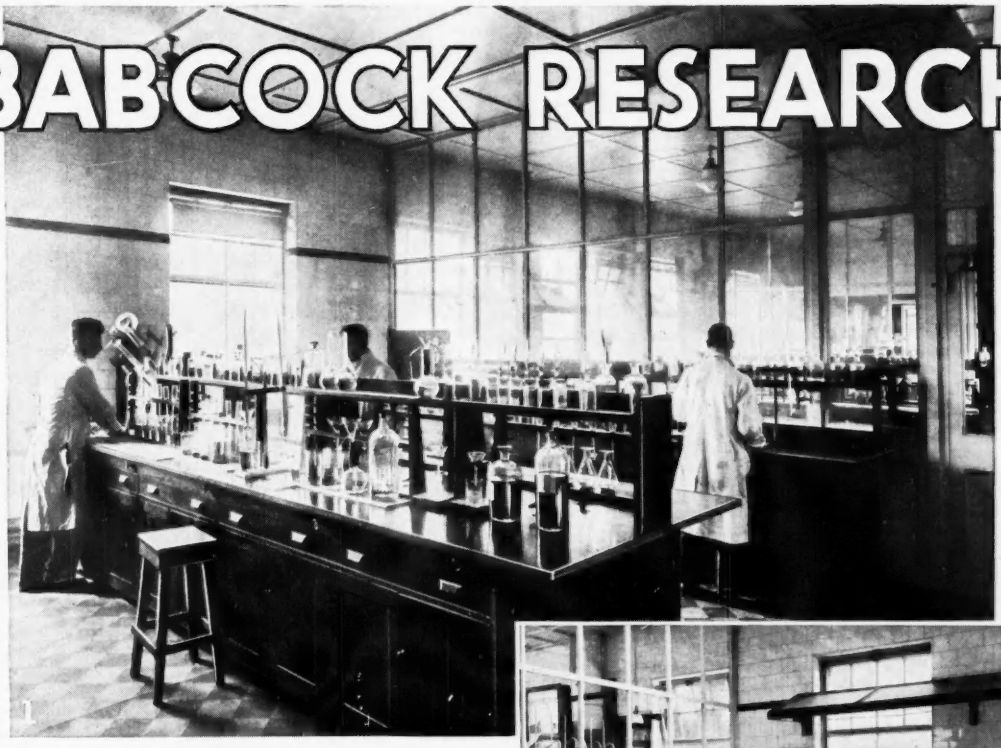
TROLLEY BUS EQUIPMENT

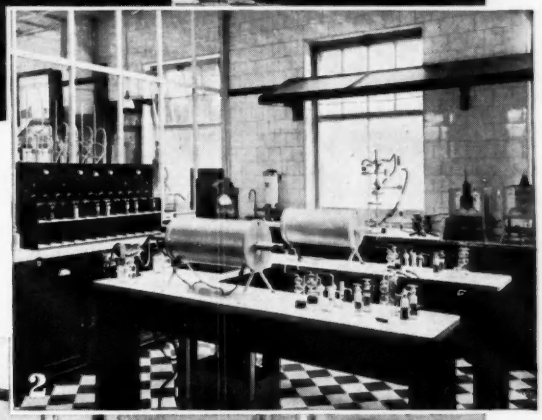


A Leyland Trolley Bus with G.E.C. electrical equipment in service at Belfast.

THE RELIABLE SERVICE ENSURED BY G.E.C.-EQUIPPED LEYLAND TROLLEY BUSES HAS LED TO THE ADOPTION OF THIS TYPE OF VEHICLE IN ALL PARTS OF THE WORLD—COPENHAGEN AND CANTON, PERTH AND PRETORIA, HOBART, DURBAN—AS WELL AS IN LONDON, BIRMINGHAM, PORTSMOUTH, READING, BELFAST AND OTHER PLACES.

BABCOCK RESEARCH





RESEARCH ADVERTISEMENT NO. 3

THE Metallurgical Section of the Babcock & Wilcox Research Laboratory is specially equipped to enable a close check to be kept on the composition of the various materials used in boiler construction and also to investigate ferrous and non-ferrous alloys. The Chemical side of this Section alone handles some 500 samples of metals per month, and an average of 150 samples are examined microscopically.

The illustrations show :—

1. A portion of the Chemical Laboratory allocated to this work.

2. Electrolysis equipment used for the electrolytic analysis of non-ferrous metals which has been so designed by the Research Department to enable these determinations to be carried out with great accuracy and speed. The centre of the same illustration shows a combustion train for the determination of carbon in metals.

3. Both in explorative and routine research the accurate determination of weight is of the highest importance and a well equipped Balance Room is indispensable. The illustration shows the Balance Room in the Babcock & Wilcox Research Department and includes special semi-micro balances of the type permitting rapidity of measurement with accuracy.

4. The Leitz Microscope and camera equipment (right) capable of a magnification of 3000 diameters. This instrument is in constant use for the examination of material forming the component parts of boilers. The Leitz Macroscope (left) is used for photographing flow lines in forgings, weld cross sections, etc., and is of importance in the development and regulation of manufacturing processes.

BABCOCK & WILCOX LTD.
34 FARRINGDON STREET, LONDON, E.C.4

THE GENERAL ELECTRIC CO.,LTD. OF ENGLAND

Known throughout the world as the

G.E.C.

MANUFACTURERS AND SUPPLIERS OF EVERYTHING ELECTRICAL

HOME BRANCHES

ABERDEEN
BELFAST
BIRMINGHAM
BLACKBURN
BLACKPOOL
BRIGHTON
BRISTOL
CARDIFF
CORK
CROYDON
DUBLIN
DUNDEE
EDINBURGH
GLASGOW
GLOUCESTER
HULL
INVERNESS
IPSWICH
LEEDS
LEICESTER
LIVERPOOL
MANCHESTER
MIDDLESBROUGH
NEWCASTLE-ON-TYNE
NOTTINGHAM
PLYMOUTH
READING
SHEFFIELD
SOUTHAMPTON
STOKE-ON-TRENT
SWANSEA

OVERSEAS BRANCHES

AUSTRALIA :
THE BRITISH GENERAL ELECTRIC CO., PTY., LTD.,
Magnet House, 104/114, Clarence Street, SYDNEY (N.S.W.).
Magnet House, 388/390, Bourke Street West, MELBOURNE (Victoria).
Magnet House, 393, Murray Street, PERTH (Western Australia).
Magnet House, 28, King Street, NEWCASTLE (N.S.W.).
55, Elizabeth Street, HOBART (Tasmania).
167, Charles Street, LAUNCESTON (Tasmania).
With Agencies in BRISBANE (Queensland), ADELAIDE (S. Australia), and New Guinea.

NEW ZEALAND :
BRITISH GENERAL ELECTRIC CO., LTD.,
31-37, Taranaki Street, WELLINGTON.
Magnet House, Gloucester Street, CHRISTCHURCH.
26, Customs Street East, AUCKLAND.

SOUTH AFRICA :
THE BRITISH GENERAL ELECTRIC CO., LTD.,
Corner of Loveday and Anderson Streets (P.O. Box No. 2406), JOHANNESBURG.
Corner of Riebeek & Lower Burg Streets (P.O. Box 1327), CAPETOWN.
20, Queen Street (P.O. Box No. 42), PORT ELIZABETH.
Magnet House, 56, Field Street, DURBAN.
With Agency in EAST LONDON (Cape Province).

NORTHERN & SOUTHERN RHODESIA :
Agencies in SALISBURY, BULAWAYO and NDOLA.

CANADA :
FRASER & CHALMERS OF CANADA, LTD.,
Crescent Building, 1411, Crescent Street, MONTREAL (Quebec).

ARGENTINA :
ANGLO-ARGENTINE GENERAL ELECTRIC CO., LTD.,
1475/1483, Rivadavia (Plaza del Congreso), BUENOS AIRES.

INDIA :
THE GENERAL ELECTRIC CO. (INDIA), LTD.,
Magnet House, Central Avenue (P.O. Box 2329), CALCUTTA.
Magnet House, Mount Road (P.O. Box No. 351), MADRAS.
Kaiser-i-Hind Building, Ballard Estate, BOMBAY.
2, Shah Din Buildings (P.O. Box 21), Charing Cross, LAHORE.
The Mall, CAWNPORE.
Magnet House, 5, South Parade, BANGALORE.
Magnet House, Main Road, TRIVANDRUM.
Magnet House, McLeod Road (P.O. Box 255), KARACHI.
Magnet House, Avanashi Road, COIMBATORE.
8-E, Inner Circle, Connaught Place, NEW DELHI.
Bashir Bagh Road, HYDERABAD (Deccan).

BURMA :
THE GENERAL ELECTRIC CO. (BURMA), LTD.,
Magnet House, 502, Merchant Street (P.O. Box 234), RANGOON.

MALAYA :
THE GENERAL ELECTRIC CO., LTD.,
Magnet House, 12, Battery Road, SINGAPORE (P.O. Box No. 203), Straits Settlements.
1, Java Street (P.O. Box No. 256), KUALA LUMPUR, SELANGOR, Federated Malay States.

CHINA :
THE GENERAL ELECTRIC CO. OF CHINA, LTD.,
49, Szechuen Road, Box No. 503, C.P.O., SHANGHAI.
G.P.O. Box No. 15, Queen's Building, HONG KONG.
Victoria Park Mansions, 202, Taku Road, TIENTSIN.
Missions Building, West Bund, CANTON.
With Agency in HANKOW.

EUROPE :
GENERAL ELECTRIC DE FRANCE LTD., 10/12, Rue Rodier, PARIS.

WORKS

Engineering Works
Witton, Birmingham
Switchgear Works
Witton, Birmingham
Transformer Works
Witton, Birmingham
High Tension Works
Witton, Birmingham
Mercury Arc Rectifier Works
Witton, Birmingham
Carbon Works
Witton, Birmingham
Lamp Black Works
Witton, Birmingham
Battery Works
Witton, Birmingham
Steel Conduit Works
Witton, Birmingham
Fan Works
Witton, Birmingham
Moulded Insulation Works
Witton, Birmingham
Telephone Works
Coventry
Radio Works
Coventry
Valve Works
Hammersmith, London
Instrument Works
Salford
Lamp Works
Hammersmith, London and Wembley, Middlesex
Accessories Works
Union Works, Wembley, Middlesex
Glass Works
Lemington-on-Tyne and Wembley
Meter Works
Birmingham
Steam-Turbine Works
Erith
Conveying and Mining Plant Works—Erith
Cable Works
Southampton and Eastleigh
Heating and Cooking Apparatus Works
Magnet Works, Birmingham
Electric Light Fittings Works
Magnet Works, Birmingham
Household Electric Appliance Works
Magnet Works, Birmingham
Electric Lifts and Escalators
Express—SMS Lift Works Northampton
Refrigerator Works
Wembley
Research Laboratories
Wembley, Middlesex

AGENCIES IN ALL THE PRINCIPAL TOWNS THROUGHOUT THE WORLD.

Head Office: **MAGNET HOUSE, KINGSWAY, LONDON, W.C.2**
Telephone : TEMPLE BAR 8000 (90 lines). *Telegrams :* "ELECTRICITY, WESTCENT, LONDON."
Cablegrams : "POLYPHASE, LONDON."

Printed by James Upton, Ltd., Barford Street, Birmingham 5, and Published by THE GENERAL ELECTRIC Co., Ltd., Magnet House, Kingsway, London, W.C.2.
PRINTED IN ENGLAND.

Bureau of Standards

MAY 24 1939

G.E.C. Journal

IN THIS ISSUE.

ELECTRICAL AND MECHANICAL EQUIPMENT AT THE EBBW VALE STEELWORKS OF RICHARD THOMAS & CO., LTD.

THE APPLICATIONS OF ELECTRIC DISCHARGE LAMPS TO PHOTOGRAPHIC PROCESSES.

THE NEW SOUND MEASUREMENT BUILDING AT WITTON.

INSTRUMENTS INCORPORATING THERMIONIC VALVES, AND THEIR CHARACTERISTICS.

RECENT PROGRESS IN ELECTRICITY METER CONSTRUCTION.

THE G.E.C. TWELVE-CHANNEL CARRIER SYSTEM FOR TELEPHONE CABLE CIRCUITS.

HIGH-FREQUENCY ELECTRIC MELTING FURNACES AT BROCKHOUSE CASTINGS, LTD.

A NOTE ON THE OPERATION OF THE PERIODICALLY IGNITED MERCURY-POOL RECTIFIER.

TECHNICAL LITERATURE.

Vol. X., No. 2. *May, 1939.*

THE GENERAL ELECTRIC CO·LTD OF ENGLAND

G.E.C.

REGD. TRADE MARK

THE LARGEST BRITISH ELECTRICAL MANUFACTURING ORGANISATION IN THE EMPIRE

Branches and Agencies throughout the world

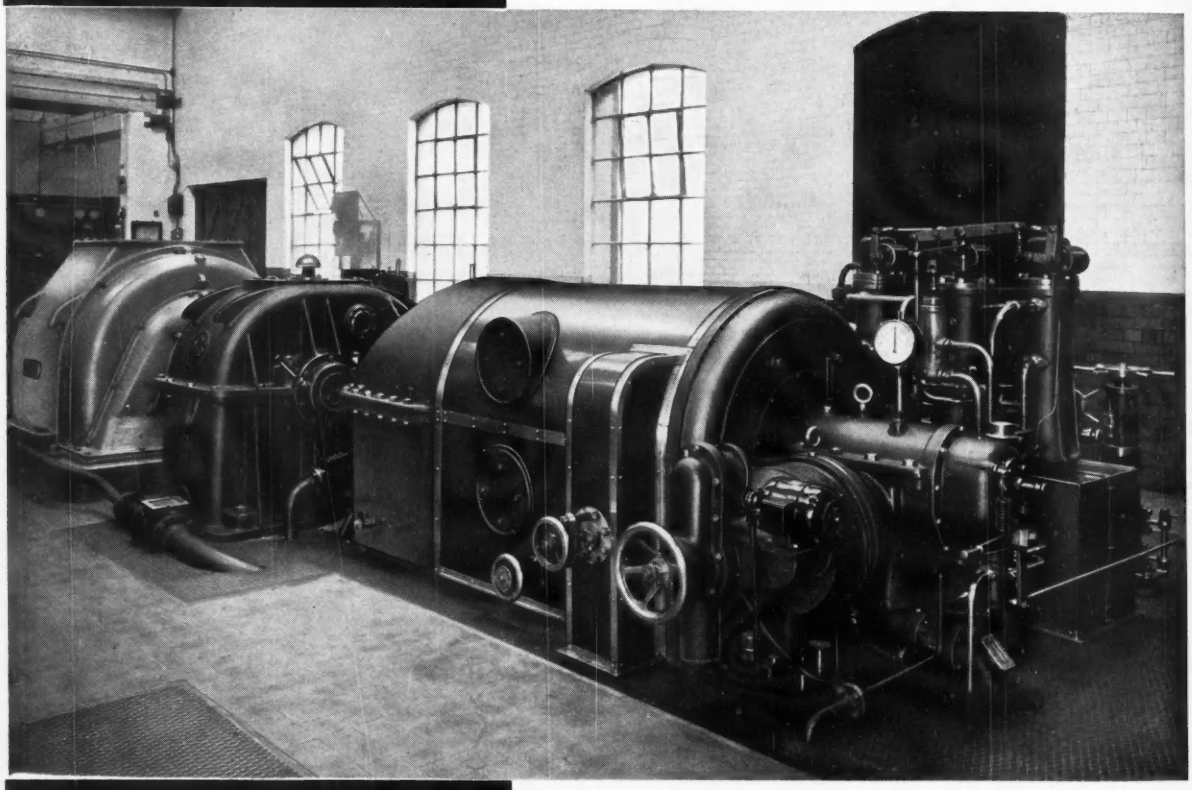
PIONEERS IN EVERY PHASE OF ELECTRICAL DEVELOPMENT

G.E.C.

FRASER AND CHALMERS

PASS-OUT TURBO PLANT

Pass-out and back pressure turbo plant enables great economies to be effected in industrial undertakings where a reasonable quantity of steam is required for process purposes



INSTALLATION AT THE FURNITURE FACTORY OF HARRIS LEBUS

This is a 2,000 kW 6,000/1,500 r.p.m. geared turbo alternator which has been running at this well-known furniture factory with highly satisfactory results over the past twelve months.

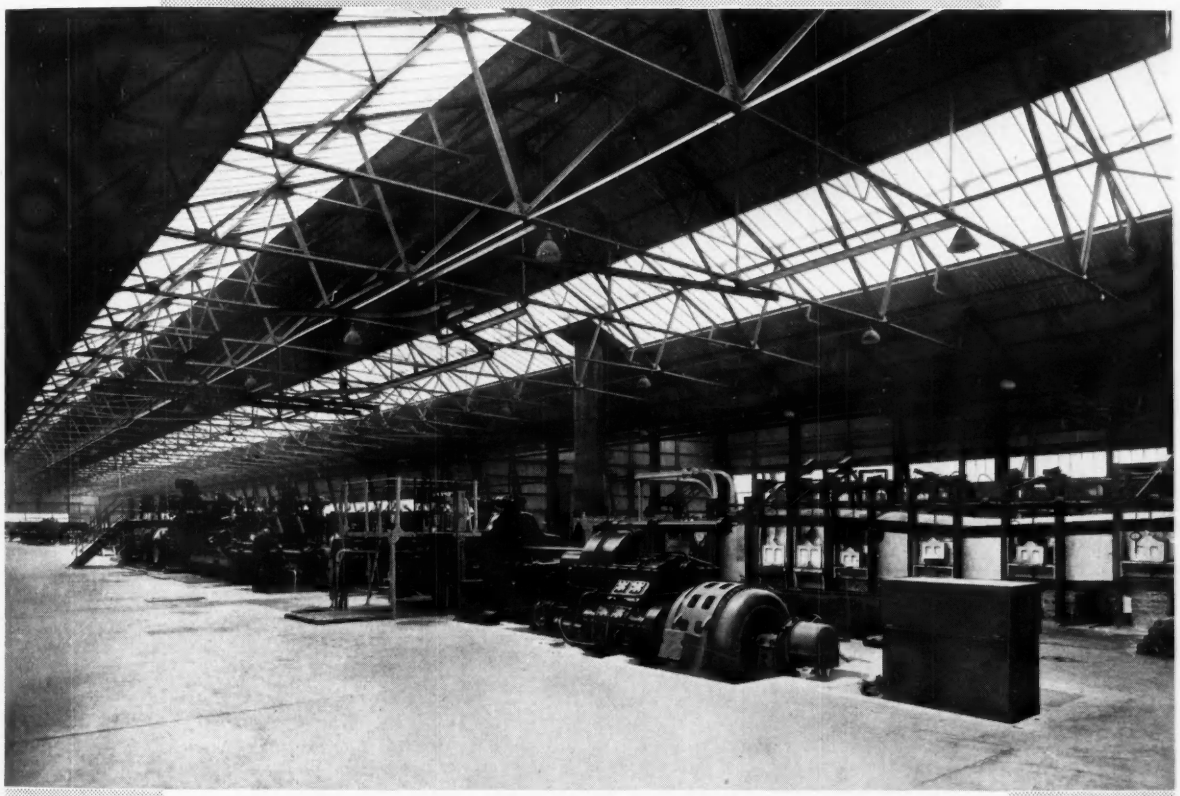
The set supplies electricity for part of the works power and lighting requirements as well as a proportion of steam for heating the works and for various process purposes.

G.E.C.

Electrical Equipment

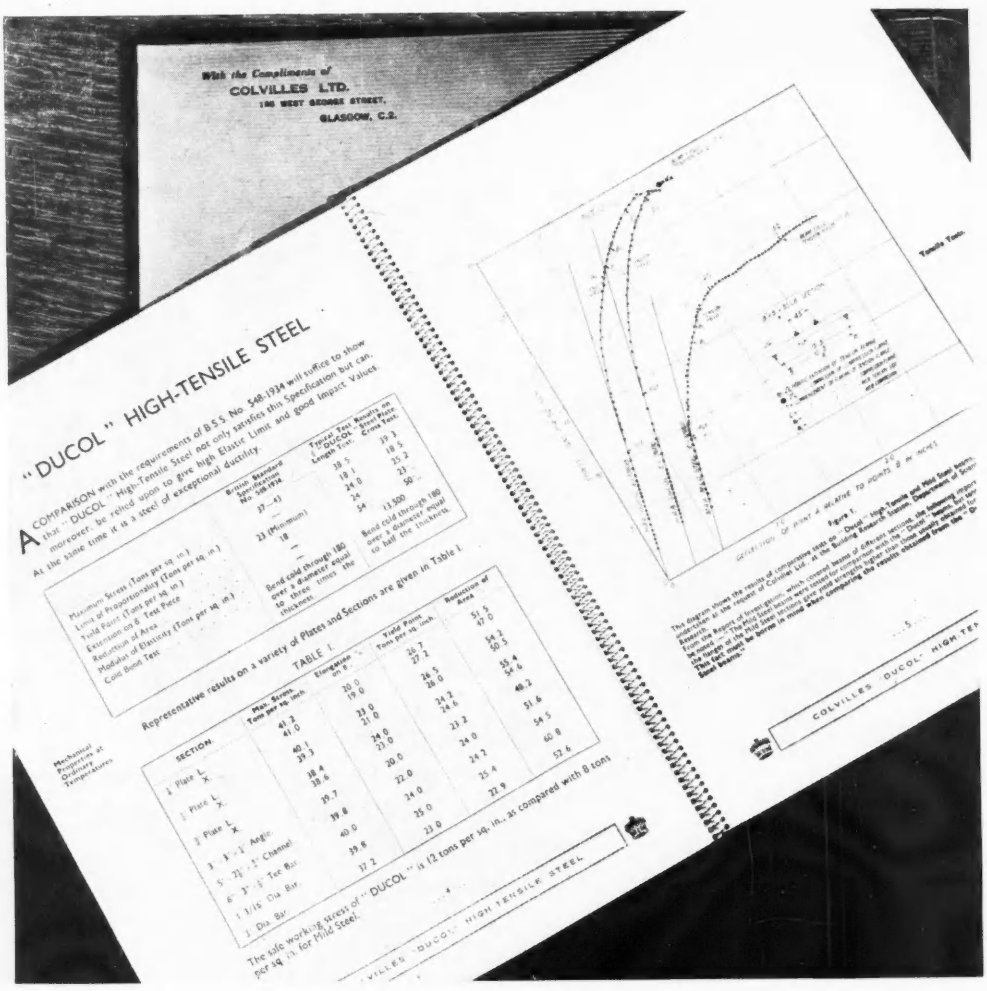
FOR

ROLLING MILLS



GENERAL VIEW OF THE MAIN ROLLING BAY AT JARROW TUBE WORKS.

The G.E.C equipment installed at this works includes motors for rolling mill and auxiliary plant drives, switchgear, cables, distribution gear, a continuous bright annealing furnace, lighting fittings and lamps, and accessory gear of many kinds.


With the Compliments of
COLVILLES LTD.
GLASGOW, C.2.
"DUCOL" HIGH-TENSILE STEEL
Representative results on a variety of Plates and Sections are given in Table I.
TABLE I.
The safe working stress of "DUCOL" is 12 tons per sq. in., as compared with 8 tons per sq. in. for Mild Steel.

High Strength, High Limit of Proportionality, High Yield Point, remarkable Ductility and Toughness, excellent Weldability, are some of the qualities which make

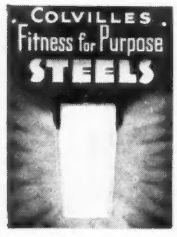
"DUCOL" HIGH-TENSILE STEEL

popular for use in the construction of Locomotives, Bridges, Tanks, Naval and Mercantile Craft, and for general Engineering and Structural purposes.

It is the Ideal Steel for use where Savings in weight are essential.

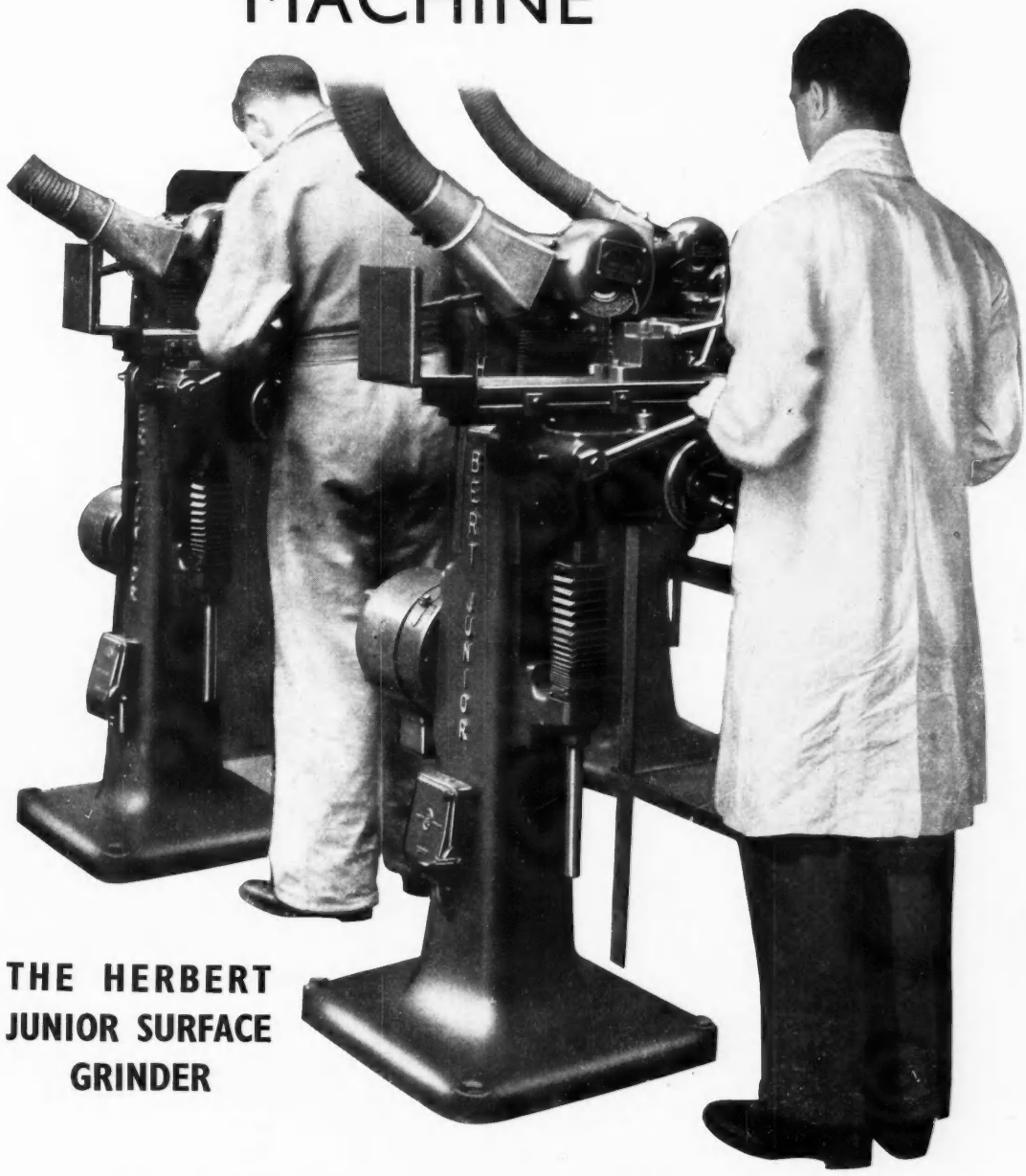
•

Write for the illustrated Brochure "Ducol" High-Tensile Steel.



COLVILLES LTD
GLASGOW SCOTLAND

EVERYBODY'S MACHINE



THE HERBERT JUNIOR SURFACE GRINDER

There is work in every shop, large or small, which will keep the Herbert Junior Surface Grinder fully occupied.

It is ideal for grinding the DIES OF COVENTRY, TANGIC, LANDIS and other Dieheads and for a wide range of tool and surface grinding which it will do more economically than larger machines.

CAPACITY: 10″ by 4″ by 9″.

DELIVERY FROM STOCK.

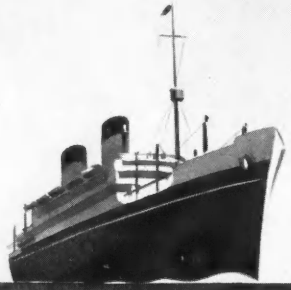
ALFRED HERBERT LTD. COVENTRY

G.E.C. LIGHTING IN THE "DOMINION MONARCH"

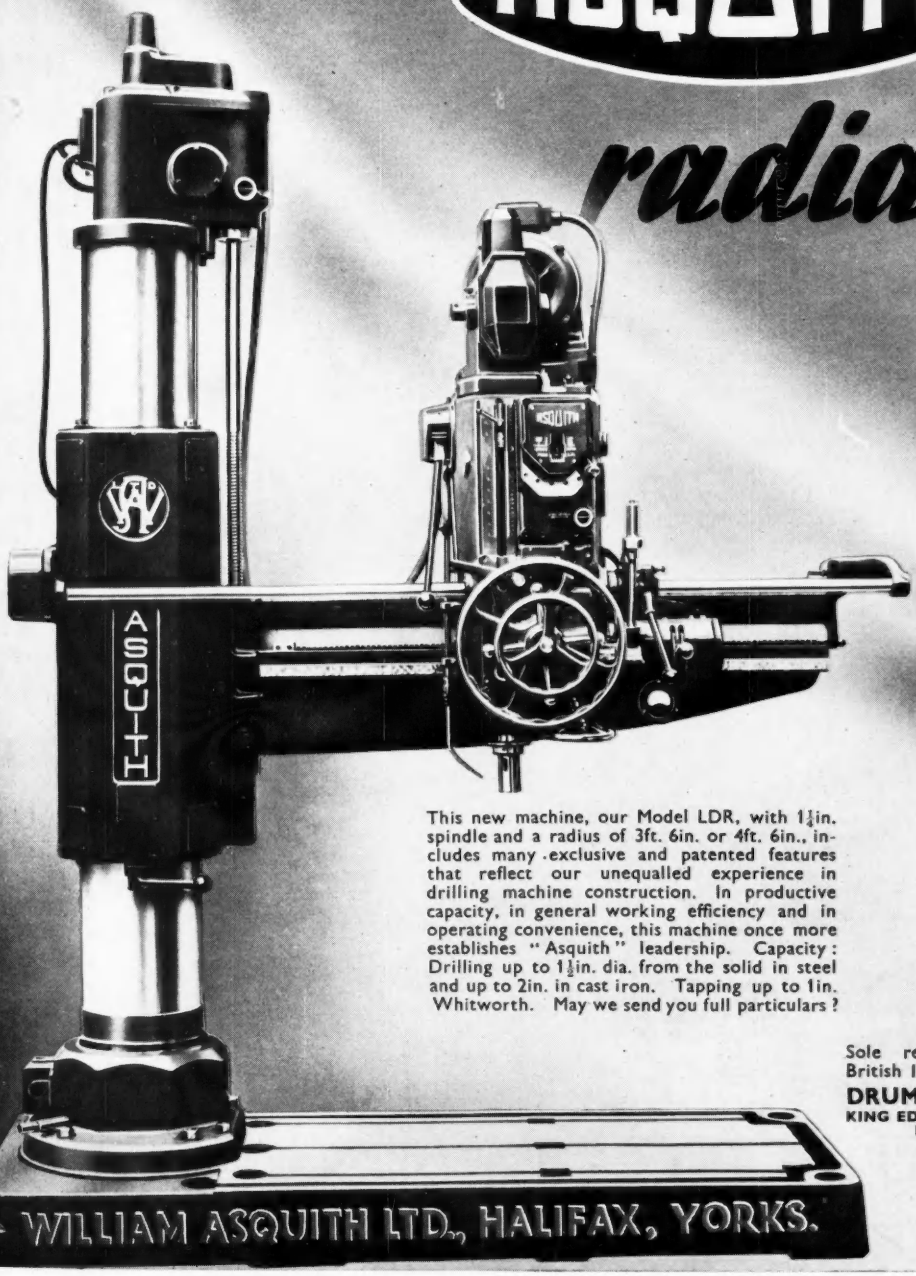
A view of the Verandah Cafe.

The "DOMINION MONARCH" is a 27,000 ton motor ship built on the Tyne for Shaw, Savill and Albion Co., Ltd. This vessel is now in service between the United Kingdom, South Africa and New Zealand.

G.E.C. lighting equipment in the ship includes a large number of decorative fittings, over 5,000 OSRAM Lamps and a special colour lighting scheme employing OSIRA triple fluorescent tubing in the Verandah Cafe, probably the largest installation of its kind in any ship.



a New ASQUITH radial!



This new machine, our Model LDR, with 1¼in. spindle and a radius of 3ft. 6in. or 4ft. 6in., includes many exclusive and patented features that reflect our unequalled experience in drilling machine construction. In productive capacity, in general working efficiency and in operating convenience, this machine once more establishes "Asquith" leadership. Capacity: Drilling up to 1½in. dia. from the solid in steel and up to 2in. in cast iron. Tapping up to 1in. Whitworth. May we send you full particulars?

Sole representatives for the British Isles:

DRUMMOND (SALES) LTD.
KING EDWARD HOUSE, NEW ST., BIRMINGHAM, 2

WILLIAM ASQUITH LTD., HALIFAX, YORKS.

Machinery

THE GENERAL ELECTRIC CO.,LTD.
OF ENGLAND

Known throughout the world as the

G.E.C.

MANUFACTURERS AND SUPPLIERS
OF EVERYTHING ELECTRICAL

HOME BRANCHES

ABERDEEN
BELFAST
BIRMINGHAM
BLACKBURN
BLACKPOOL
BRIGHTON
BRISTOL
CARDIFF
CORK
CROYDON
DUBLIN
DUNDEE
EDINBURGH
GLASGOW
GLOUCESTER
HULL
INVERNESS
IPSWICH
LEEDS
LEICESTER
LIVERPOOL
MANCHESTER
MIDDLESBROUGH
NEWCASTLE-ON-TYNE
NOTTINGHAM
PLYMOUTH
READING
SHEFFIELD
SOUTHAMPTON
STOKE-ON-TRENT
SWANSEA

OVERSEAS BRANCHES

AUSTRALIA :
THE BRITISH GENERAL ELECTRIC CO., PTY., LTD.
Magnet House, 104/114, Clarence Street, SYDNEY (N.S.W.).
Magnet House, 388/390, Bourke Street West MELBOURNE (Victoria).
Magnet House, 393, Murray Street, PERTH (Western Australia).
Magnet House, 28, King Street, NEWCASTLE (N.S.W.).
55, Elizabeth Street, HOBART (Tasmania).
167, Charles Street, LAUNCESTON (Tasmania).
With Agencies in BRISBANE (Queensland), ADELAIDE S. Australia), and New Guinea

NEW ZEALAND :
BRITISH GENERAL ELECTRIC CO., LTD.
31-37, Taranaki Street, WELLINGTON.
Magnet House, Gloucester Street, CHRISTCHURCH
26, Customs Street East, AUCKLAND

SOUTH AFRICA :
THE BRITISH GENERAL ELECTRIC CO., LTD.,
Corner of Loveday and Anderson Streets (P.O. Box No. 2406), JOHANNESBURG.
Corner of Riebeek & Lower Burg Streets (P.O. Box 1327), CAPETOWN.
20, Queen Street (P.O. Box No. 42), PORT ELIZABETH.
Magnet House, 56, Field Street, DURBAN.
With Agency in EAST LONDON (Cape Province).

NORTHERN & SOUTHERN RHODESIA
THE BRITISH GENERAL ELECTRIC CO., LTD.,
4/5, Brest Buildings (P.O. Box 1070), BULAWAYO.
Wetherby House, Baker Avenue (P.O. Box 845), SALISBURY.
With Agency in NDOLA.

CANADA :
FRASER & CHALMERS OF CANADA, LTD.
Crescent Building, 1411, Crescent Street, MONTREAL (Quebec).

ARGENTINA :
ANGLO-ARGENTINE GENERAL ELECTRIC CO., LTD.,
1475/1483, Rivadavia (Plaza del Congreso), BUENOS AIRES.

INDIA :
THE GENERAL ELECTRIC CO. (INDIA), LTD.,
Magnet House, Central Avenue (P.O. Box 2329), CALCUTTA.
Magnet House, Mount Road (P.O. Box No. 351), MADRAS.
Kaiser-i-Hind Building, Ballard Estate, BOMBAY.
2, Shah Din Buildings (P.O. Box 21), Charing Cross, LAHORE.
The Mall, CAWNPORE.
Magnet House, 5, South Parade, BANGALORE.
Magnet House, Main Road, TRIVANDRUM.
Magnet House, McLeod Road (P.O. Box 255), KARACHI.
Magnet House, Avanashi Road, COIMBATORE.
8-E, Inner Circle, Connaught Place, NEW DELHI.
Bashir Bagh Road, HYDERABAD (Deccan).

BURMA :
THE GENERAL ELECTRIC CO. (BURMA), LTD.,
Magnet House, 502, Merchant Street (P.O. Box 234), RANGOON.

MALAYA :
THE GENERAL ELECTRIC CO., LTD.,
Magnet House, 12, Battery Road, SINGAPORE (P.O. Box No. 203), Straits Settlements.
1, Java Street (P.O. Box No. 256), KUALA LUMPUR, SELANGOR, Federated Malay States.
With Agencies in PENANG, IPOH and SERAMBAN.

CHINA :
THE GENERAL ELECTRIC CO. OF CHINA, LTD.
Magnet House, 49, Szechuen Rd.(Box No.503, C.P.O.), SHANGHAI
G.P.O. Box No. 15, Queen's Buuding, HONG KONG.
Victoria Park Mansions, 202, Taku Road, TIENTSIN
Missions Building, West Bund, CANTON.
With Agency in HANKOW.

EUROPE :
GENERAL ELECTRIC DE FRANCE LTD., 10/12, Rue Rodier, PARIS.

WORKS

Engineering Works
Witton, Birmingham
Switchgear Works
Witton, Birmingham
Transformer Works
Witton, Birmingham
High Tension Works
Witton, Birmingham
Mercury Arc Rectifier Works
Witton, Birmingham
Carbon Works
Witton, Birmingham
Lamp Black Works
Witton, Birmingham
Battery Works
Witton, Birmingham
Steel Conduit Works
Witton, Birmingham
Fan Works
Witton, Birmingham
Moulded Insulation Works
Witton, Birmingham
Telephone Works
Coventry
Radio Works
Coventry
Valve Works
Hammersmith, London
Instrument Works
Salford
Lamp Works
Hammersmith, London and Wembley, Middlesex
Accessories Works
Union Works, Wembley, Middlesex
Glass Works
Lemington-on-Tyn. and Wembley
Meter Works
Birmingham
Steam-Turbine Works
Erith
Conveying and Mining Plant Works—Erith
Cable Works
Southampton and Eastleigh
Heating and Cooking Apparatus Works
Magnet Works, Birmingham
Electric Light Fittings Works
Magnet Works, Birmingham
Household Electric Appliance Works
Magnet Works, Birmingham
Electric Lifts and Escalators
Express—SMS Lift Works Northampton
Refrigerator Works
Wembley
Research Laboratories
Wembley, Middlesex

AGENCIES IN ALL THE PRINCIPAL TOWNS THROUGHOUT THE WORLD.

Head Office: **MAGNET HOUSE, KINGSWAY, LONDON, W.C.2**
Telephone : TEMPLE BAR 8000 (90 lines). *Telegrams :* " ELECTRICITY, WESTCENT, LONDON."
Cablegrams : " POLYPHASE, LONDON."

Printed by James Upton, Ltd., Barford Street, Birmingham 5, and Published by THE GENERAL ELECTRIC Co., Ltd., Magnet House, Kingsway, London, W.C.2.
PRINTED IN ENGLAND.

Bureau of Standards

SEP 7 1939

G.E.C. Journal

IN THIS ISSUE.

COGGING MILL MODERNIZATION AND NEW MERCHANT MILL INSTALLATION DORMAN, LONG & CO., LTD.

COLOUR & COLOUR RENDERING.

INSTRUMENTS INCORPORATING THERMIONIC VALVES, & THEIR CHARACTERISTICS PART II.

PLASTICS AND THE ELECTRICAL INDUSTRY.

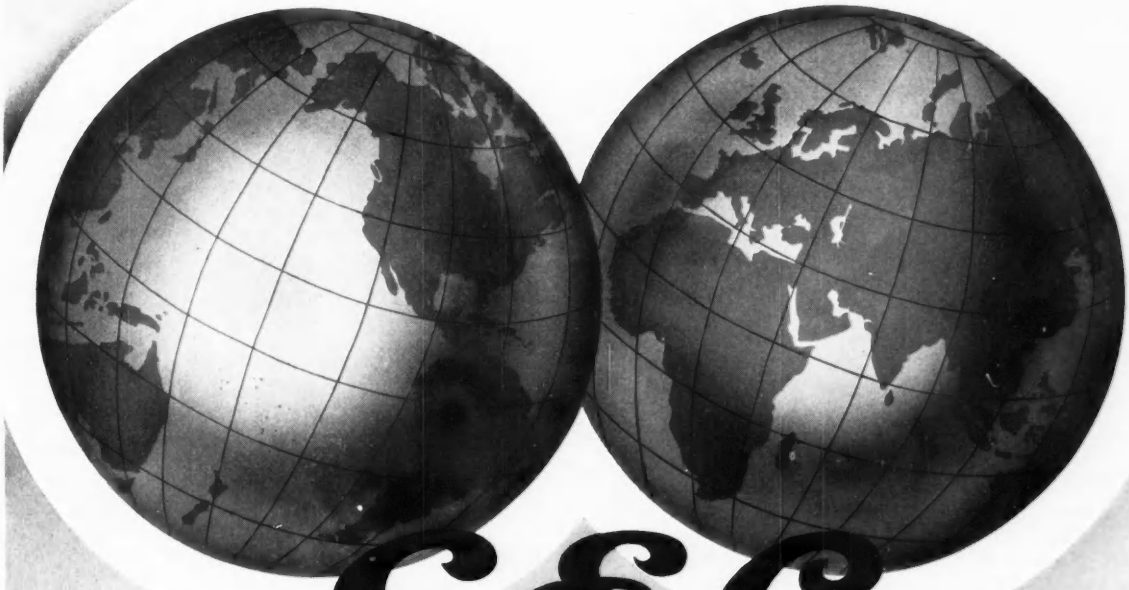
THE ELECTRICAL EQUIPMENT OF TRINIDAD PAPER PULP MILL.

A UNIDIRECTIONAL SYSTEM FOR THE LIGHTING OF DOUBLE-CARRIAGEWAY & ONE-WAY ROADS

THE DESIGN OF FRACTIONAL HORSE-POWER MOTORS PART I.

Vol. X., No. 3. *August, 1939.*

THE GENERAL ELECTRIC CO·LTD OF ENGLAND



G.E.C.

REGD. TRADE MARK

THE LARGEST BRITISH ELECTRICAL MANUFACTURING ORGANISATION IN THE EMPIRE

Branches and Agencies throughout the world

PIONEERS IN EVERY PHASE OF ELECTRICAL DEVELOPMENT

TOURIST CLASS LOUNGE

G.E.C.

LIGHTING

The General Electric Co. Ltd., was entrusted with the lighting schemes and the manufacture and supply of the lighting fittings for the various public rooms listed on opposite page. A most effective combination of illumination and decoration is achieved in these sections of the ship, as can be seen in the representative views here reproduced

CABIN CLASS LOUNGE

CABIN CLASS
OBSERVATION LOUNGE

ON THE T.S.S "MAURETANIA"

TOURIST CLASS SMOKE ROOM

G.E.C. Lighting Fittings are installed in the following rooms:—

CABIN CLASS

DINING SALOON
LOUNGE
VERANDAH CAFE
OBSERVATION LOUNGE
SWIMMING POOL

TOURIST CLASS

SMOKE ROOM
LOUNGE
PLAYROOM
CINEMA

CABIN CLASS VERANDAH CAFE

Other G.E.C. Electrical Equipment

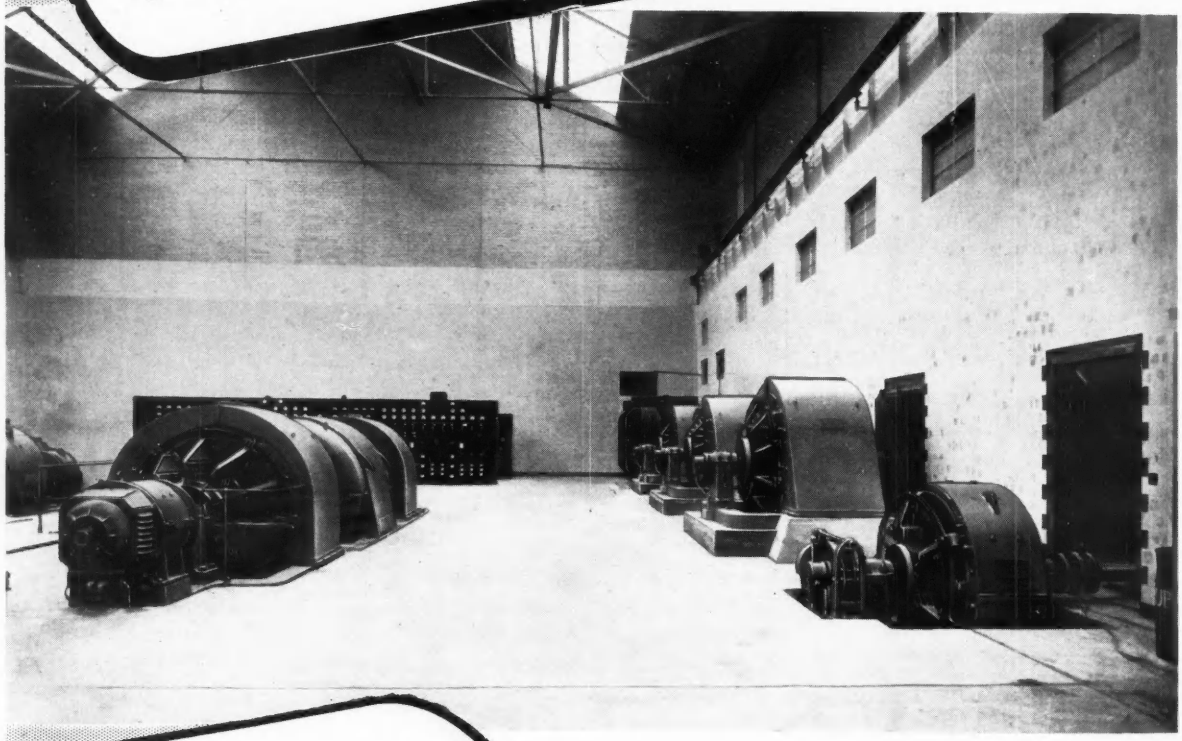
includes

MOTORS. Super silent marine motors are used throughout the ship for driving the ventilating fans; a total of 113 d.c. motors.

LIFTS. Eleven Express—S.M.S. lifts are installed, five for passengers and six for goods service. The passenger lifts are attendant-operated and equipped to give automatic and accurate levelling at each deck.

TOURIST CLASS NURSERY

G.E.C. ELECTRICAL EQUIPMENT for IRON AND STEELWORKS



INSTALLATION AT THE EBBW VALE WORKS OF RICHARD THOMAS & CO., LTD.

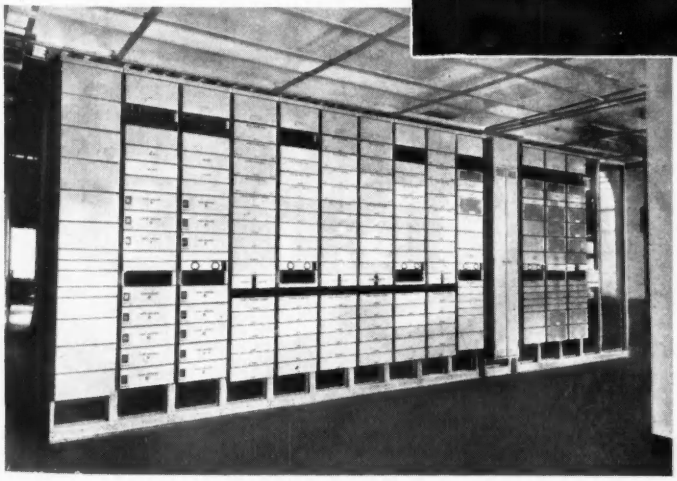
A large quantity of G.E.C. electrical and mechanical plant is employed in this great undertaking—one of the largest steel production centres in Great Britain.

The contract for G.E.C. equipment included electric motors totalling over 16,000 h.p. in capacity, control gear, switchboards and transformers, as well as over 2,000 tons of mechanical gear—manufactured at Fraser & Chalmers Engineering Works.

Above is a view of the main motor room of the cold mill with three 1,500 h.p. and one 400 h.p. D.C. motors, a 4,000 kVA Ward-Leonard set, and a control switchboard.

G.E.C. TWELVE-CHANNEL CARRIER SYSTEM FOR TELEPHONE TRUNK LINES

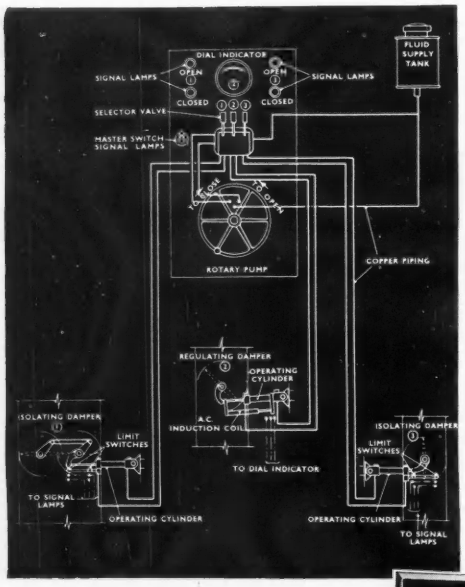
● TERMINAL AND THROUGH STATIONS



G.E.C. twelve-channel carrier terminal equipment in Faraday Building, London.

The twelve-channel carrier system is an outstanding development in telephone transmission, and it is now being applied extensively to British Post Office Trunk lines between cities.

The system enables one telephone line to carry up to twelve conversations simultaneously. The map shows routes on the British Post Office Trunk Telephone network for which G.E.C. twelve-channel carrier equipment is either in operation or in course of installation.



THE LOCKHEED BABCOCK *Hydraulic Remote* DAMPER CONTROL

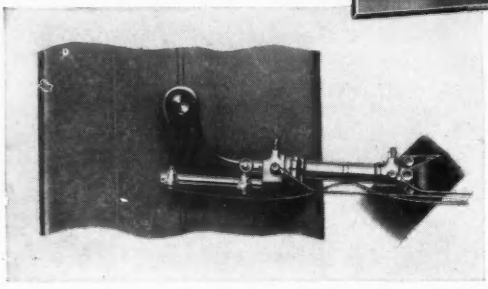
A NEW DEVELOPMENT OF GREAT IMPORTANCE

ABOVE is a diagrammatic lay-out of Lockheed-Babcock Hydraulic Remote Damper Control Gear.

On the right is a typical panel with 24 control points, 16 of which are of the isolating type and indicate on pairs of electric lights, showing red for fully open and green for fully closed.

The remaining 8 are of the regulating type and indicate on the dial the position of their respective dampers. The necessary electrical connections are incorporated in the hydraulic selector valves.

Rotation of the handwheel in the direction required opens or closes the selected damper.



On the left is shewn a typical arrangement of the Isolating, Indication Type, Autoloc Slave Cylinder as applied to a single damper, operating in a horizontal plane.

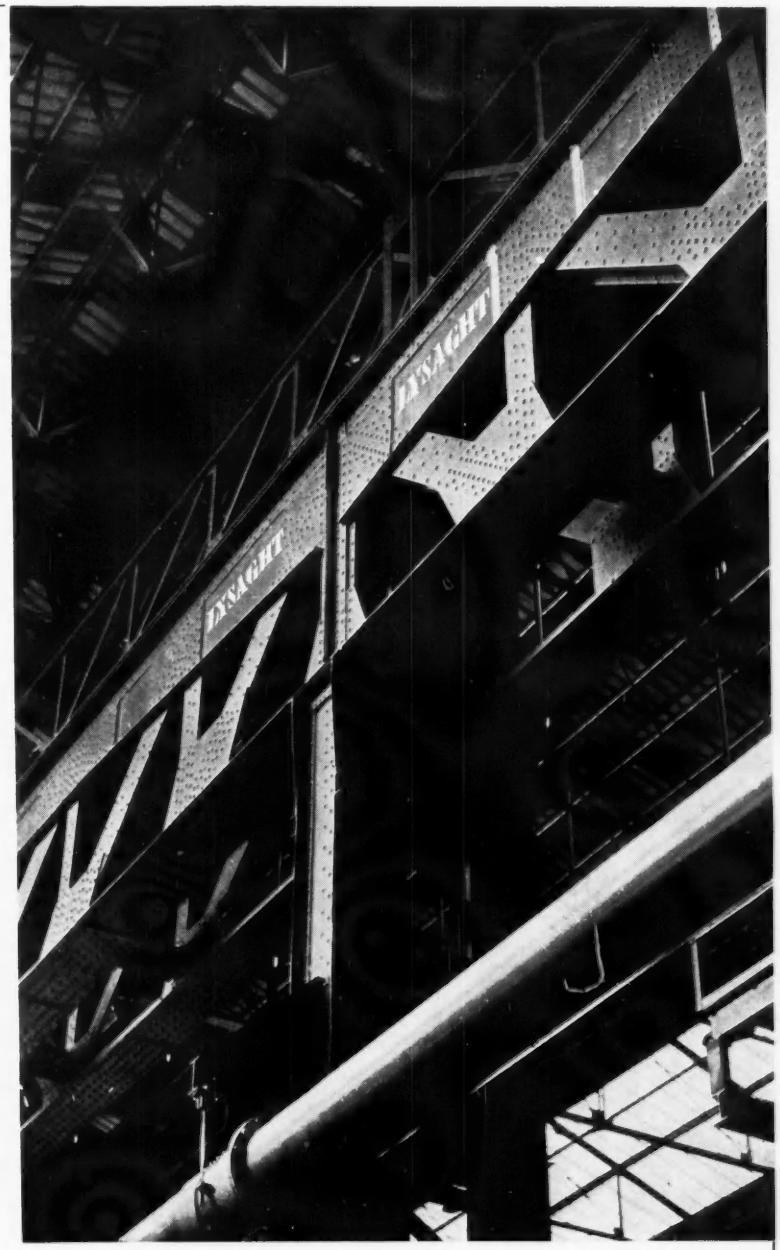
These Slave cylinders can be equally well installed for operating in a vertical plane.

Pairs of Synchronised Autoloc Slave Cylinders can also be arranged, where two dampers, situated some distance apart, have to be operated simultaneously.

A copy of our catalogue No. 1273 describing this control will be sent on application.

BABCOCK & WILCOX LTD.

BABCOCK HOUSE, 34 FARRINGDON STREET, LONDON, E.C.4.



Lysaght products include high grade steel bars, billets, blooms, slabs and pig iron from the Scunthorpe Works ; sheet steel and galvanised sheets in every quality from Newport, Mon. ; Constructional work of all kinds from Bristol, and chilled rolls and general castings from Wolverhampton. Abroad: the Lysaght Organisation manufactures black or galvanised sheets in Australia and galvanised sheets in Canada and South America.

JOHN LYSAGHT

L I M I T E D

ORB IRON WORKS, NEWPORT, MON.

a new radial of advanced design

Only Asquith experience and resources can produce an Asquith Radial

In this new radial, our type L.D.R., Asquith specialized experience has produced a machine which has won instant leadership. No other radial drill includes all the features of this machine.

Here are a few points. Patented arm design giving extra rigidity under heavy cuts. Patented speed and feed selection and indication ; the feed and the speed both shown in one aperture ; and all speeds obtained by a single lever. Easy gear change : no "inching." Spindle slide and arm both locked at once by one lever. Automatic trip to feed with special scale for point correction, incorporating a device which prevents the feed being re-engaged, once the trip has operated, until the drill has been withdrawn.

The machine embodies all that the name "Asquith" means in materials, workmanship and performance. It is available with 3ft. 6in. and 4ft. 6in. radius, with spindle 1¾in. dia., No. 4 Morse taper end.

Write now for descriptive leaflet.

Manufacturers :

WILLIAM ASQUITH LTD.,
Halifax, Yorks.

Telephone : Halifax 61258-9
Telegrams : Drill, Halifax

ASQUITH

Sole agents for the British Isles :

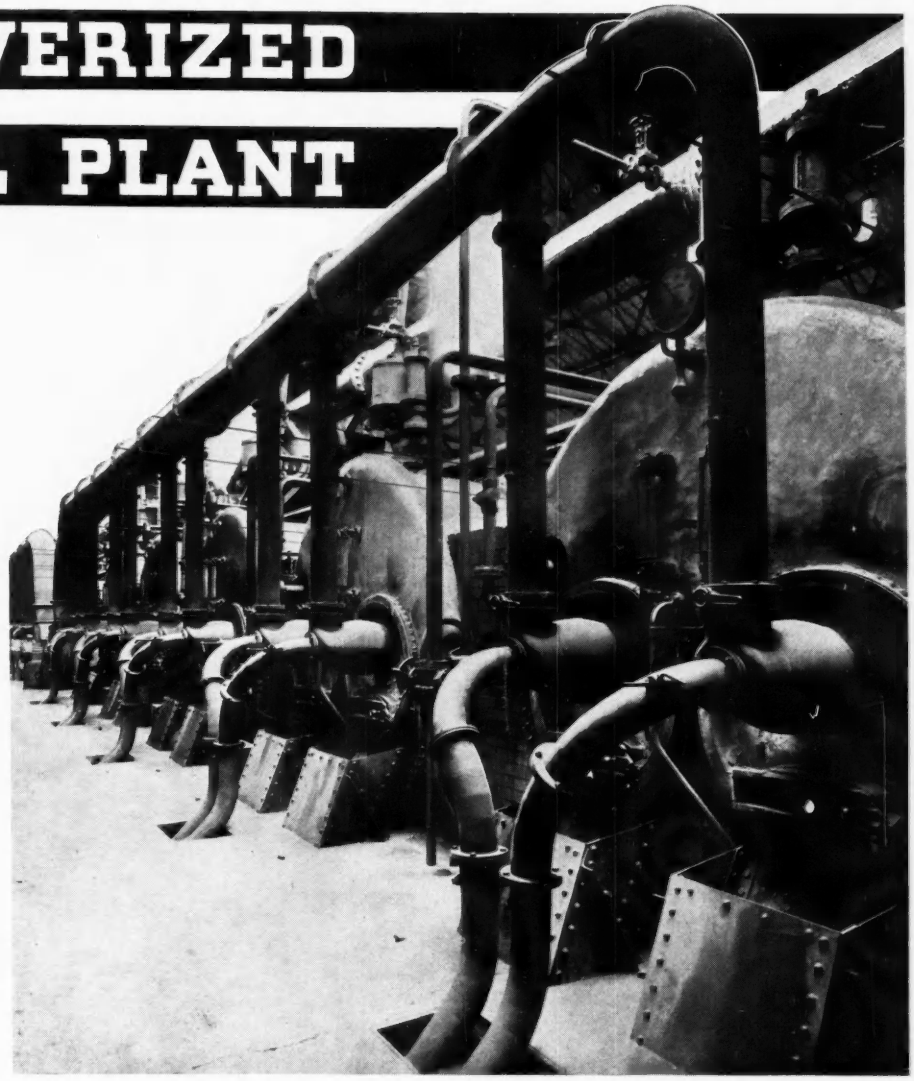
DRUMMOND SALES LTD.,
King Edward House, New St., Birmingham

Telephone : Midland 3431
Telegrams : Maxishape, Birmingham

G.E.C.

FRASER & CHALMERS

PULVERIZED FUEL PLANT



INSTALLATION AT CHATTERLEY WHITFIELD COLLIERIES LTD., TUNSTALL, STOKE-ON-TRENT

This plant comprises a complete coal storage, milling, feeding and burning equipment for ten 30ft. x 9ft. Lancashire boilers fitted with economisers and superheaters. The layout is in two batteries of five boilers, each with a 100 ton pulverized coal storage bunker and Hardinge mill of 5 tons per hour capacity.

THE GENERAL ELECTRIC CO., LTD.
OF ENGLAND

Known throughout the world as the

G.E.C.

MANUFACTURERS AND SUPPLIERS
OF EVERYTHING ELECTRICAL

HOME BRANCHES

ABERDEEN
BELFAST
BIRMINGHAM
BLACKBURN
BLACKPOOL
BRIGHTON
BRISTOL
CANTERBURY
CARDIFF
CORK
CROYDON
DUBLIN
DUNDEE
EDINBURGH
GLASGOW
GLOUCESTER
HULL
INVERNESS
IPSWICH
LEEDS
LEICESTER
LIVERPOOL
LUTON
MANCHESTER
MIDDLESBROUGH
NEWCASTLE-ON-TYNE
NOTTINGHAM
PLYMOUTH
READING
SHEFFIELD
SOUTHAMPTON
STOKE-ON-TRENT
SWANSEA

OVERSEAS BRANCHES

AUSTRALIA :
THE BRITISH GENERAL ELECTRIC CO., PTY., LTD.
Magnet House, 104/114, Clarence Street, SYDNEY (N.S.W.).
Magnet House, 388/390, Bourke Street West, MELBOURNE (Victoria).
Magnet House, 393, Murray Street, PERTH (Western Australia)
Magnet House, 28, King Street, NEWCASTLE (N.S.W.).
55, Elizabeth Street, HOBART (Tasmania).
167, Charles Street, LAUNCESTON (Tasmania).
With Agencies in BRISBANE (Queensland), ADELAIDE (S. Australia), and New Guinea.

NEW ZEALAND :
BRITISH GENERAL ELECTRIC CO., LTD.
31-37, Taranaki Street, WELLINGTON.
Magnet House, Gloucester Street, CHRISTCHURCH.
26, Customs Street East, AUCKLAND.

SOUTH AFRICA :
THE BRITISH GENERAL ELECTRIC CO., LTD.,
Corner of Loveday and Anderson Streets (P.O. Box No. 2406), JOHANNESBURG.
Corner of Riebeek & Lower Burg Streets (P.O. Box 1327), CAPETOWN.
20, Queen Street (P.O. Box No. 42), PORT ELIZABETH.
Magnet House, 56, Field Street, DURBAN.
With Agency in EAST LONDON (Cape Province).

NORTHERN & SOUTHERN RHODESIA
THE BRITISH GENERAL ELECTRIC CO., LTD.,
4/5, Brest Buildings (P.O. Box 1070), BULAWAYO.
Wetherby House, Baker Avenue (P.O. Box 845), SALISBURY.
With Agency in NDOLA.

CANADA :
FRASER & CHALMERS OF CANADA, LTD.
Crescent Building, 1411, Crescent Street, MONTREAL (Quebec).

ARGENTINA :
ANGLO-ARGENTINE GENERAL ELECTRIC CO., LTD.,
1475/1483, Rivadavia (Plaza del Congreso), BUENOS AIRES.

INDIA :
THE GENERAL ELECTRIC CO. (INDIA), LTD.,
Magnet House, Central Avenue (P.O. Box 2329), CALCUTTA.
Magnet House, Mount Road (P.O. Box No. 351), MADRAS.
Kaiser-i-Hind Building, Ballard Estate, BOMBAY.
2, Shah Din Buildings (P.O. Box 21), Charing Cross, LAHORE.
The Mall, CAWNPORE.
Magnet House, 5, South Parade, BANGALORE.
Magnet House, Main Road, TRIVANDRUM.
Magnet House, McLeod Road (P.O. Box 255), KARACHI.
Magnet House, Avanashi Road, COIMBATORE.
8-E, Inner Circle, Connaught Place, NEW DELHI.
Bashir Bagh Road, HYDERABAD (Deccan).

BURMA :
THE GENERAL ELECTRIC CO. (BURMA), LTD.,
Magnet House, 502, Merchant Street (P.O. Box 234), RANGOON.

MALAYA :
THE GENERAL ELECTRIC CO., LTD.,
Magnet House, 12, Battery Road, SINGAPORE (P.O. Box No. 203), Straits Settlements.
1, Java Street (P.O. Box No. 256), KUALA LUMPUR, SELANGOR, Federated Malay States.
With Agencies in PENANG, IPOH and SERAMBAN.

CHINA :
THE GENERAL ELECTRIC CO. OF CHINA, LTD.
Magnet House, 49, Szechuen Rd.(Box No.503, C.P.O.), SHANGHAI
G.P.O. Box No. 15, Queen's Building, HONG KONG.
Victoria Park Mansions, 202, Taku Road, TIENTSIN
Missions Building, West Bund, CANTON
With Agency in HANKOW.

FRANCE :
GENERAL ELECTRIC DE FRANCE LTD., 10/12, Rue Rodier PARIS.

WORKS

Engineering Works
Witton, Birmingham
Switchgear Works
Witton, Birmingham
Transformer Works
Witton, Birmingham
High Tension Works
Witton, Birmingham
Mercury Arc Rectifier Works
Witton, Birmingham
Carbon Works
Witton, Birmingham
Lamp Black Works
Witton, Birmingham
Battery Works
Witton, Birmingham
Steel Conduit Work
Witton, Birmingham
Fan Works
Witton, Birmingham
Moulded Insulation Works
Witton, Birmingham
Telephone Works
Coventry
Radio Works
Coventry
Valve Works
Hammersmith, London
Instrument Works
Salford
Lamp Works
Hammersmith, London and Wembley, Middlesex
Accessories Works
Union Works, Wembley, Middlesex
Glass Works
Lemington-on-Tyne and Wembley
Meter Works
Birmingham
Steam-Turbine Works
Erith
Conveying and Mining Plant Works—Erith
Cable Works
Southampton and Eastleigh
Heating and Cooking Apparatus Works
Magnet Works, Birmingham
Electric Light Fittings Works
Magnet Works, Birmingham
Household Electric Appliance Works
Magnet Works Birmingham
Electric Lifts and Escalators
Express—SMS Lift Works Northampton
Refrigerator Works
Wembley
Research Laboratories
Wembley, Middlesex

AGENCIES IN ALL THE PRINCIPAL TOWNS THROUGHOUT THE WORLD.

Head Office: **MAGNET HOUSE, KINGSWAY, LONDON, W.C.2**
Telephone: TEMPLE BAR 8000 (90 lines). *Telegrams:* "ELECTRICITY, WESTCENT, LONDON."
Cablegrams: "POLYPHASE, LONDON."

Printed by James Upton, Ltd., Barford Street, Birmingham 5, and Published by THE GENERAL ELECTRIC Co., Ltd., Magnet House, Kingsway, London, W.C.2.
PRINTED IN ENGLAND.